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FOREST-SITE QUALITY STUDIES IN THE ADIRONDACKS

I. TREE GROWTH AS RELATED TO SOIL MORPHOLOGY

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FOREST-SITE QUALITY STUDIES IN THE ADIRONDACKS

I. TREE GROWTH AS RELATED TO SOIL MORPHOLOGY[1]

ROY L. DONAHUE

The investigation here reported included in its scope the growth of commercial forest trees as related to soil morphology in the central Adirondack Mountains of New York State. In addition, several factors were measured that are sometimes correlated with growth: namely, light intensity, ground vegetation, specific gravity of the wood, and tree-root distribution.

The common and scientific names of the trees mentioned throughout this memoir, as given by George B. Sudworth in *Check List of the Forest Trees of the United States, Their Names and Ranges* (U. S. Agr. Dept., Misc. circ. 92:1–295, 1927), are listed below.

Common name	Scientific name
Ash, black	*Fraxinus nigra* Marsh.
Ash, mountain	*Sorbus americana* Marsh.
Ash, white	*Fraxinus americana* L.
Aspen	*Populus tremuloides* Michx.
Basswood	*Tilia glabra* Vent.
Beech	*Fagus grandifolia* Ehrh.
Birch, paper	*Betula papyrifera* Marsh.
Birch, yellow	*Betula lutea* Michx.
Cedar, northern white	*Thuja occidentalis* L.
Elm, American	*Ulmus americana* L.
Fir, balsam	*Abies balsamea* (L.) Mill.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Maple, mountain	*Acer spicatum* LaMarck
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pennsylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Pine, northern white	*Pinus strobus* L.
Pine, Norway	*Pinus resinosa* Solander
Pine, shortleaf	*Pinus echinata* Mill.
Spruce, black	*Picea mariana* (Mill.) BSP.
Spruce, red	*Picea rubra* Link
Spruce, white	*Picea glauca* (Moench) Voss
Tamarack	*Larix laricina* (DuRoi) Koch

REVIEW OF LITERATURE

To review all of the literature bearing on the general subject of tree growth would require more space than is justified by the limitations of this memoir. Hence only those publications that pertain directly to the associated relationships of tree growth and field-soil characteristics are here mentioned. In addition, a few basic references used in the initiation and interpretation of this work are included in the appropriate places.

Hilgard (1911) was among the first in the United States to study and report the fact that tree form and growth are intimately associated with the soil. His sketches of the various forms assumed by several species of trees on contrasting soils first awakened in the writer a keen interest in forest

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[1] Contribution from the Forest Soils Laboratory at Cornell University, directed by the Charles Lathrop Pack Research Professor in Forest Soils. Also presented to the Faculty of the Graduate School of Cornell University, September 1939, as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENTS. The author gratefully acknowledges helpful criticisms and suggestions from his special committee, consisting of Dr. R. F. Chandler, Jr. (chairman), Professor A. B. Recknagel, and Dr. R. A. Mordoff. He is indebted to H. T. Hopkins, Jr., graduate student at Cornell University, for general field assistance; to T. H. Crawshaw, forester for Finch, Pruyn & Co. of Glens Falls, for assistance in locating suitable forest stands for the investigation; and to Dr. E. F. Wallihan, assistant professor of forestry at Cornell University, for supplying and installing the soil-moisture tensiometers used in the study. Special mention is due also to John S. Robas for photographing the increment borings.

soils. Hilgard's conclusions can most cogently be summarized in his own words (page 487 of reference cited): "Next to climatic conditions, chief among which are temperature and moisture, the physical and chemical nature of the soil and subsoil is the most potent factor in determining the natural vegetation of any region."

The observations and measurements made on the Harvard Forest by Fisher (1928) gave rise to a renewed study of the interrelationships between soil-profile development and forest composition. After 18 years of hardwood growth (which followed old-field northern white pine), a podzolized raw-humus soil became transformed into a fine mull with a high population of earthworms. White ash and sugar maple were particularly effective in this transformation. Similar conclusions were drawn by Griffith, Hartwell, and Shaw (1930) when they studied the decrease in thickness of the organic layer and of the leached A_2 horizon where hardwoods followed pines.

Authorities disagree as to the time required for noticeable changes to take place in the soils under forested conditions. Kittredge (1930), in discussing the importance of time and rate of change in forest-soil investigations, cited Fisher's time of 18 years, and Tamm's (1920) findings of 1000 to 1500 years, as the minima for significant changes to be brought about in the soil.

Using the silt-plus-clay content of the soil as a measure of site quality, Haig (1929) reported a fair degree of correlation with the height growth of Norway-pine plantations in Connecticut. Hicock and others (1931) concluded that "Soil series, soil texture, character of the A_0 horizon and character of the subsoil, each considered individually, can all be correlated with site index, but the degree of correlation is rather low in each case." Lunt (1932), in a comprehensive investigation of New England forest-soil profiles, reported that the soil itself is usually dominant over the composition of the forest in influencing the type of profile formed. This is essentially the same conclusion as that reached by Plice (1934). Kittredge (1938), in a thorough field study in Minnesota and Wisconsin, summarized his findings in part by saying: "The soil profiles offer the best foundation for the differentiation and prediction of the productivity of the different habitats for the growth of aspen."

A somewhat different approach to the complex problem of site classification was proposed and demonstrated in the Adirondack Mountains of New York by Heimburger (1934). Using plant-indicator types as indexes of site quality, he described the plant associations and gave them names from their key species. This technique has much to commend it. The greatest single objection lies in the fact that only a trained botanist can use this system of classifying sites. Other objections are (1) that its use is limited to virgin or near-virgin forest conditions, and (2) that each region may require a separate classification.

THE REGION

CLIMATE

Climatic data, summarized from all records (including those for 1938) of the twenty-eight cooperative weather-bureau stations in the Adirondack

Park,[2] revealed: (1) an evenly distributed precipitation of about 3 to 4 inches for each month of the year, with a maximum during July (figure 1); (2) mean monthly temperatures that, when graphed, were similar to a normal frequency curve having July at its apex and February as the month of lowest temperatures (figure 1); (3) snowfall recorded for each month of the year for at least one station,[3] with February at the peak (figure 2); (4) short summers, with a range of 79 to 162 days frost-free; (5) prevailing westerly winds throughout the year. (United States Weather Bureau, 1934; Mordoff, 1934.)

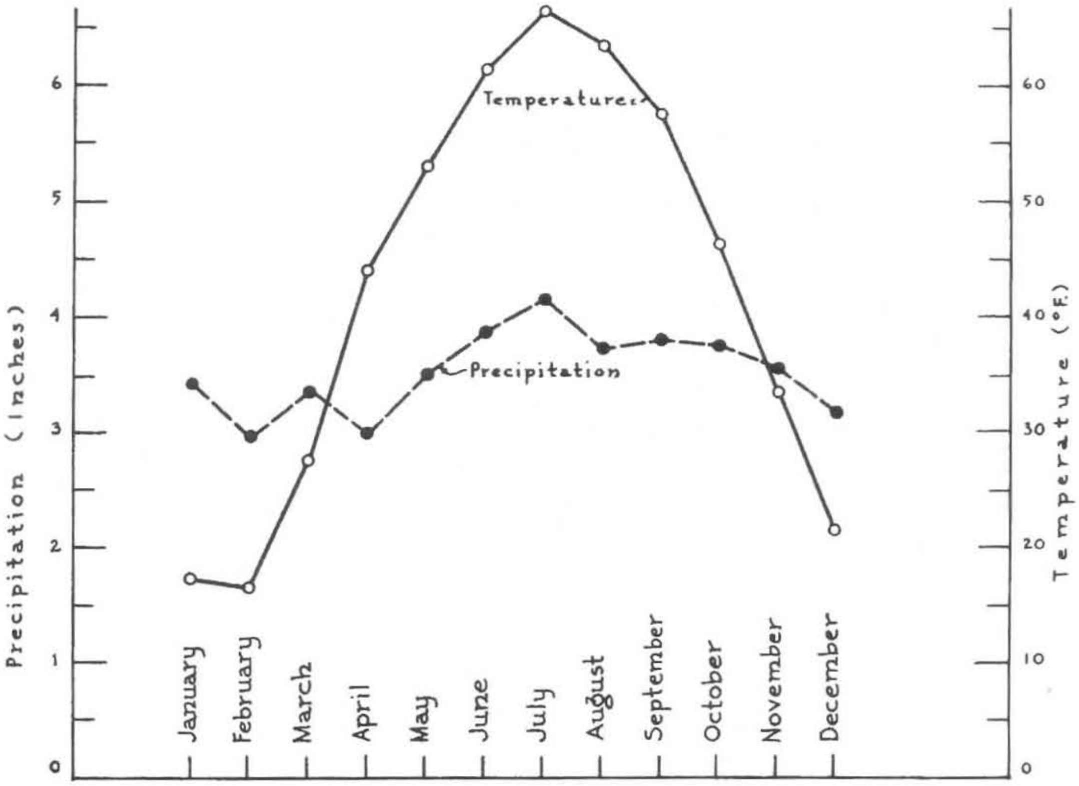

FIGURE 1. MEAN MONTHLY PRECIPITATION AND MEAN MONTHLY TEMPERATURE FOR THE ADIRONDACK PARK

GEOLOGY

The Adirondack Mountains are old, rounded, mature, isolated peaks or groups of peaks composed chiefly of Adirondack gneiss[4] with old intrusions of anorthosite, a rock containing soda-lime feldspar. Outcrops of Grenville crystalline limestone (among the oldest rocks of North America) are found in several localities (Balk, 1932). The valleys are broad, are approximately parallel, and run northeast–southwest. Bowman (1914) stated that the main valleys originated as graben fault blocks, carved and reshaped by subsequent glacial and stream erosion. Tarr (1902), however, made little mention of this explanation for the origin of the valleys.

Elevations in the Adirondacks range mostly between 1500 and 2000 feet.

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[2] "The Adirondack Park" is a specific name for the area of 4,604,000 acres inside the "Blue Line" which delimits the land to be acquired by the State in the Adirondack region.

[3] Snowfall for June, July, and August was very light, with Blue Mountain Lake, Gabriels, Lake Placid, Nehasane, Tupper Lake, and Wanakena each reporting at least a trace for June, Gabriels a trace for July, and Blue Mountain Lake a trace for August.

[4] Adirondack gneiss is a syenite granite of gneissic structure.

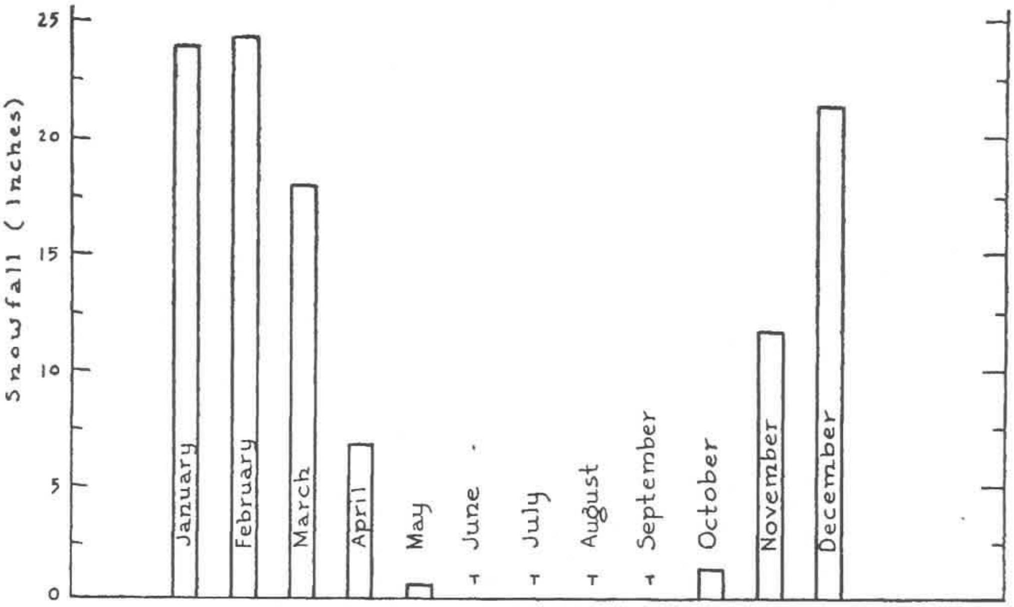

FIGURE 2. MEAN MONTHLY SNOWFALL FOR THE ADIRONDACK PARK

There are several peaks rising above 4000 feet, and Mount Marcy, the highest mountain in the region, is 5344 feet high.

SOILS

The striking features of the soils are: (1) their shallowness to bedrock; (2) their sandy texture; and (3) their heterogeneity. The broad valleys usually contain stratified sand and gravel, while the slopes and ridges have a shallow soil mantle which has developed from soil material deposited by the continental ice sheet. Small bodies of peat soil have formed in certain land-locked depressions. The entire Adirondacks lies in the Podzol soil region (United States Department of Agriculture, 1938).

FORESTS

At one time all of the Adirondack region, with the exception of the lakes and a few mountain peaks, was covered with some type of forest. Clearing of the more productive soils has slightly altered this land pattern, but the region is still predominantly forested. M. Westveld (1930) has divided the spruce forests into five types: spruce flat, spruce hardwoods, spruce slope, spruce swamp, and old-field spruce. In addition to the types in which spruce occurs, isolated patches of virtually pure hardwoods are found on some of the lower slopes.

PLOT TECHNIQUE

METHOD OF SELECTION

Before going into the field, the writer solicited ideas and opinions from many persons regarding the best method of selecting the plots for growth investigation in relation to visual differences in the soil. Two general plans were considered: (1) to choose noticeable and contrasting soils in fully stocked virgin or near-virgin stands, and record the tree growth thereon; or (2) to choose widely different virgin stands having several commercially important species in common, and then to examine and study the soil supporting these trees as well as recording the tree growth. The latter method was decided upon.

The next step consisted in locating in the field such fully stocked virgin or near-virgin stands as showed differences in growth form yet contained several species in common. The original plan was to select paired hardwood plots, each set of which contained sugar maple, beech, and yellow birch; and paired softwood plots, each set supporting spruce, balsam fir, and northern white cedar.

For the selection of the hardwood plots an idea was gleaned from Chandler (1937) to the effect that, if the distribution of basswood and American elm is associated with their high calcium requirements, then a forest containing these species would be supported by a relatively high calcium soil and hence a productive soil.

The commercially valuable hardwood species chosen for study were sugar maple, beech, and yellow birch. To find suitable stands of these species associated with a scattering of either American elm, white ash (also a high-calcium-requiring tree), or basswood, proved to be extremely difficult. The solution to this problem came when a collector[5] of ginseng (*Panax quinquefolium*) revealed the fact that this plant grows only under conditions similar to those demanded by the above situation; that is, in a dense hardwood stand containing American elm, white ash, and/or basswood.[6]

In contrast to these so-called "rich" forest conditions, other stands[7] were chosen which supported the three hardwood species—sugar maple, beech, and yellow birch—and, in addition, either spruce,[8] balsam fir, or eastern hemlock.

Selection of the softwood plots for the purpose of comparing the growth of spruce, balsam fir, and northern white cedar, represented a different procedure. After exhaustive field examinations it was finally decided to study the comparative growth of these species on a spruce flat[9] and on a spruce swamp[10] forest type.

The plot locations are shown in figure 3.

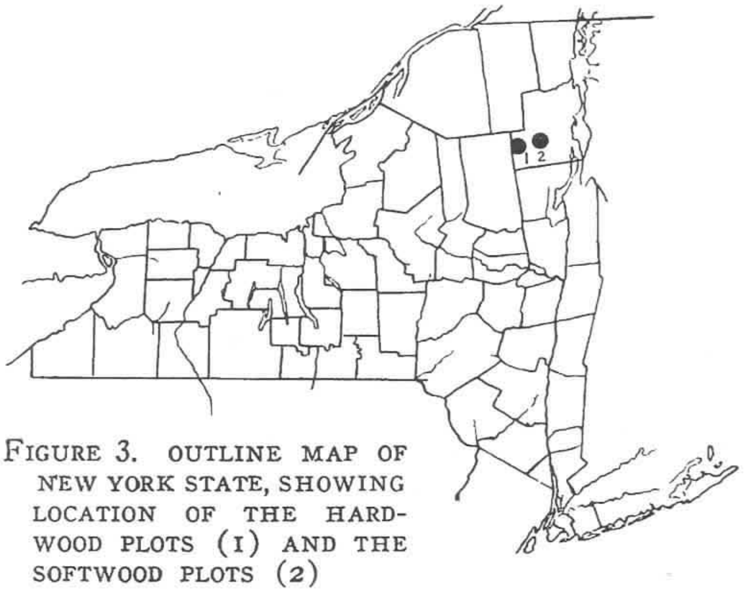

FIGURE 3. OUTLINE MAP OF NEW YORK STATE, SHOWING LOCATION OF THE HARDWOOD PLOTS (1) AND THE SOFTWOOD PLOTS (2)

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[5] Floyd Parker, of Newcomb, New York, to whom thanks are due.

[6] This forest type corresponded roughly to type no. 12 of the Society of American Foresters (1932)—"sugar maple—beech—yellow birch." It is hereinafter referred to as "hardwood."

[7] Corresponding to "red spruce—sugar maple—beech", type no. 17 of the Society of American Foresters (1932) but here designated as "spruce-hardwood."

[8] In this dissertation, "spruce" refers to both red spruce (*Picea rubra* Link) and black spruce (*Picea mariana* [Mill.] BSP.). An attempt was made in the field to separate the species, but difficulty was encountered in the swamps. Probably 95 per cent or more of the "spruce" was red spruce.

[9] Type no. 18 of the Society of American Foresters (1932), designated as "red spruce."

[10] Type no. 23 of the Society of American Foresters (1932), designated as "black spruce." The actual number of typical black spruce found was small, however. The red spruce and the black spruce in the swamp were difficult to separate, and so both were here termed "spruce."

PLAN OF THE PLOTS

Quadruplicate plots, each 1 acre in size, were laid out at different locations on each of the four forest types chosen for study. A compass-and-chain traverse was made to determine the most representative acre.[11] Each acre was then subdivided into sixteen equal compartments, white string being used around these compartments for guide lines. At the intersections of these strings, and also on the periphery of the entire plot, stakes were driven, and these stakes, 25 in all, were numbered consecutively for points of reference.

Methods of selecting, measuring, and computing forest and soil characteristics, and of charting and summarizing the tree roots, are discussed later, along with the data.

ANALYSIS OF FOREST CHARACTERISTICS

STAND COMPOSITION

In the hardwood forest type (figure 5), sugar maple outnumbered all the other species combined. Next, in numerical order of the dominant and co-dominant trees, was beech, followed by basswood, yellow birch, white ash, and American elm. From the stand graph (figure 4) it can readily be seen that the mode of all diameters[12] ranged between 15 and 25 inches d.b.h. (diameter breast high), and that the largest trees reached 35 inches d.b.h.

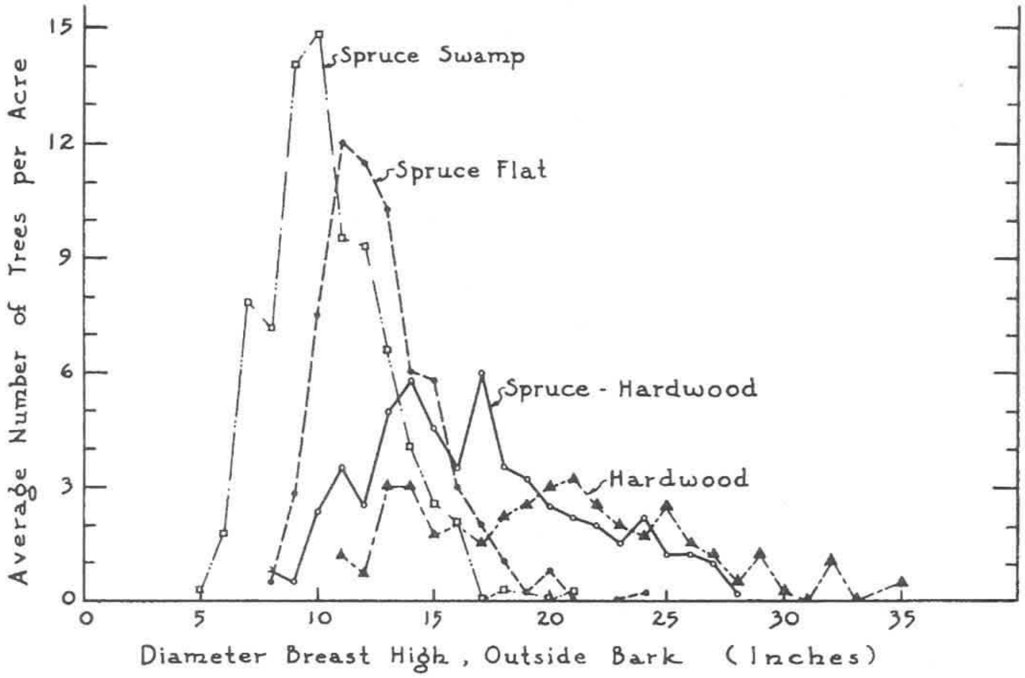

FIGURE 4. STAND GRAPH, SHOWING THE AVERAGE DISTRIBUTION PER ACRE OF THE DIAMETER CLASSES BY FOREST TYPES

The predominant species comprising the spruce-hardwood type (figure 6) were yellow birch and sugar maple. Next, in numerical order, were beech, spruce, red maple, balsam fir, and eastern hemlock. The diameters of the trees averaged slightly lower than those in the hardwood type, and

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[11] With the exception of two swamp plots, all of the plots were 208.7 feet (3.16 chains) on each side, making them 1 acre in size. These two swamp plots were made irregular so that the entire area of each would be confined to the true swamp.

[12] All diameters were measured with a diameter tape, at a height of 4.5 feet.

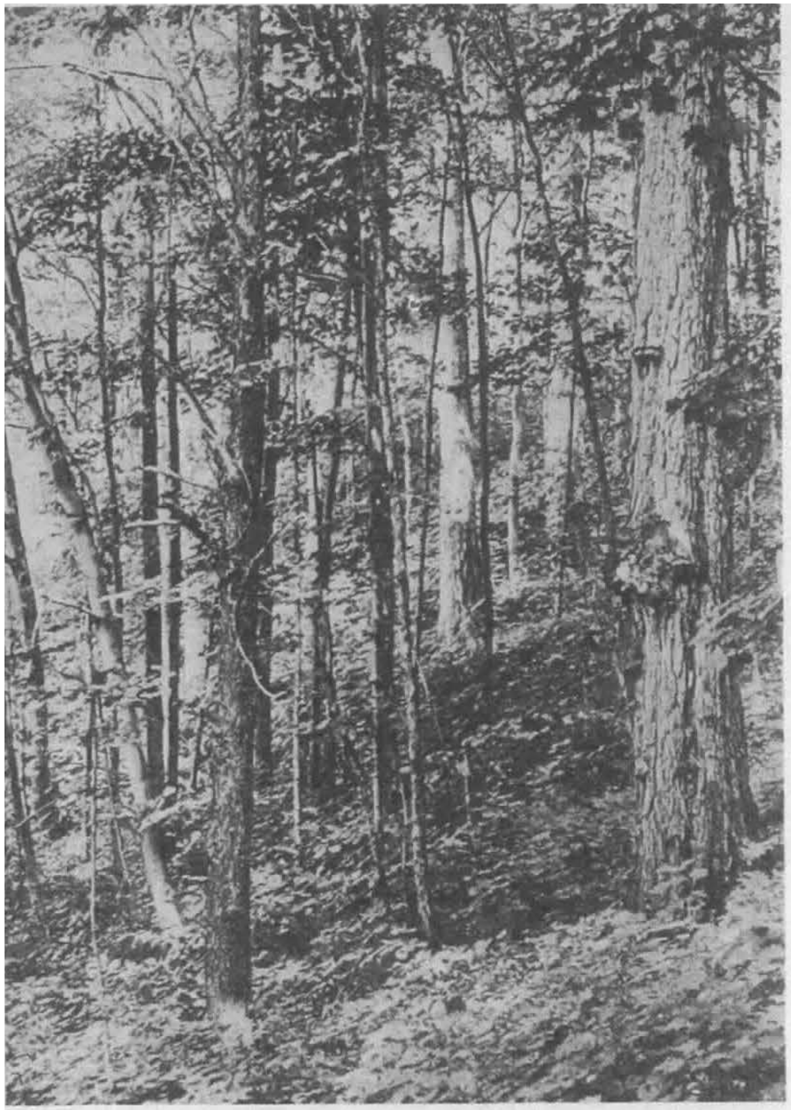

FIGURE 5. REPRESENTATIVE HARDWOOD FOREST TYPE

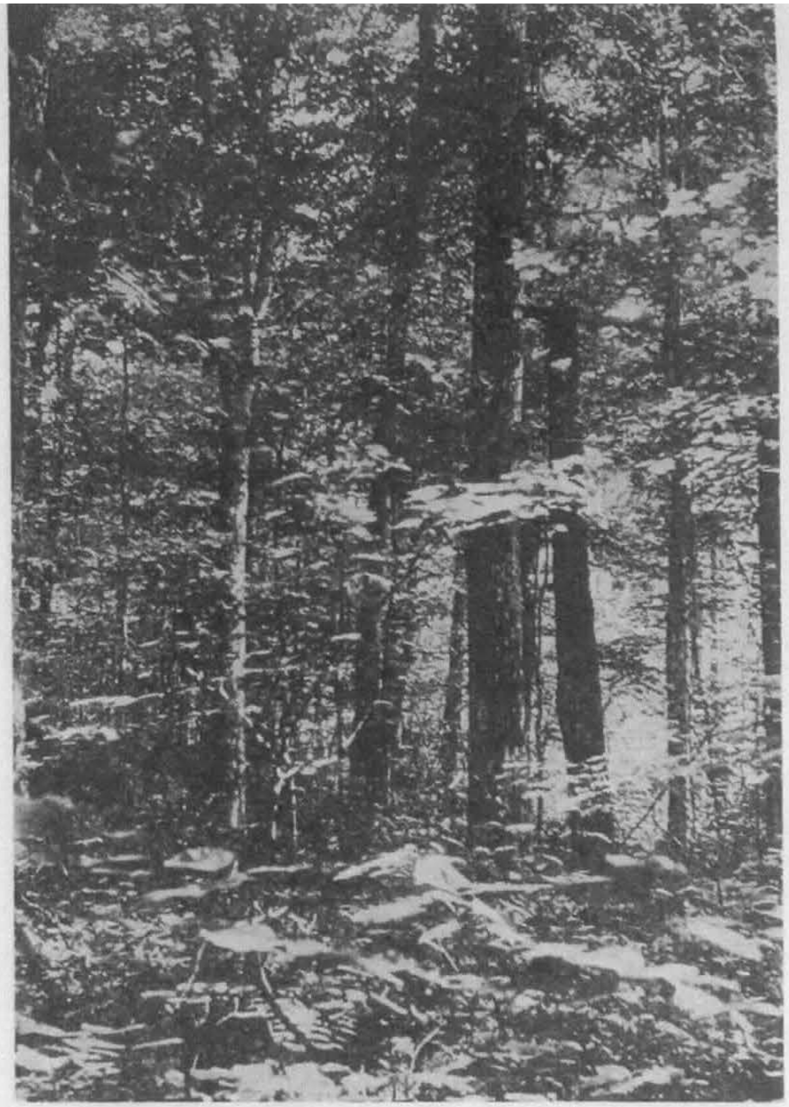

FIGURE 6. REPRESENTATIVE SPRUCE-HARDWOOD FOREST TYPE

the largest tree was only 28 inches d.b.h. as compared with 35 inches d.b.h. in the hardwood type.

Balsam fir and spruce together accounted for 224 out of a total of 250 trees tallied on 4 acres of the spruce flat type (figure 7). Minor species present were yellow birch, northern white cedar, paper birch, and red maple, in the order named. The diameters of the trees showed a high frequency at 11 inches d.b.h.

The spruce swamp type (figure 8) appears to have been, in this case, improperly named. "Balsam swamp" or "softwood swamp" would have been a more appropriate name, since more than half of the trees were balsam fir. Only about one-fourth of the trees were spruce, followed in numerical order by northern white cedar, tamarack, yellow birch, and paper birch. As the stand graph strikingly shows, the d.b.h. of greatest frequency was 10 inches and the largest d.b.h. was 21 inches.

TOTAL HEIGHT OF TREES AT MATURITY

Many methods are proposed in forestry literature for use as indexes of site quality. Among these may be mentioned: height-over-age; height at maturity; basal area; specific gravity of the wood; mean annual increment in cubic feet and in pounds of oven-dry wood;[13] radial growth; plant-indicator types; and certain soil characteristics such as soil-profile development, silt-plus-clay content, and hydrogen-ion concentration.

In this investigation, all of the above indexes except height-over-age[14] were measured on the same forest stands and their relative merits were compared.

Total height of the dominant and co-dominant trees at a given age or at maturity has been used as an index of site quality for many years. This method of determining the productive capacity of the site was strongly advocated by Roth (1916), Watson (1917), and Frothingham (1918). Also, it has been used generally in European yield tables.

The height of each dominant and co-dominant tree in the acre plots was measured, a Forest Service standard hypsometer being used. With the conifers, very little difficulty was encountered in sighting the exact tops of the trees through the hypsometer. Such was not the case, however, with the hardwoods. With large, spreading, flat-topped wolf trees, the highest limb was almost impossible to locate. Less emphasis should therefore be given to differences in the heights of the hardwoods, although the errors in measurement should compensate.

On the hypothesis that trees with the more exacting site requirements[15] are limited in their distribution to the more fertile soils, it might be expected that other species in association would show a more favorable growth. A glance at figure 9 will support this view. With the softwoods (figure 10) also the same relationships hold, but here there is one exception: balsam fir growing on the spruce-hardwood type averaged 3 feet less in height than it did when growing on the spruce flat type. This inconsistency may be explained by the fact that only 9 trees served as a basis for the average height on the spruce-hardwood type. To support the contention that more

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[13] It is not known whether mean annual increment in pounds of oven-dry wood has been used as an index of site quality previous to the present investigation.

[14] Height-over-age as a site index is better adapted to young even-aged stands than to old-growth all-aged stands such as were used here.

[15] Species such as American elm, white ash, and basswood.

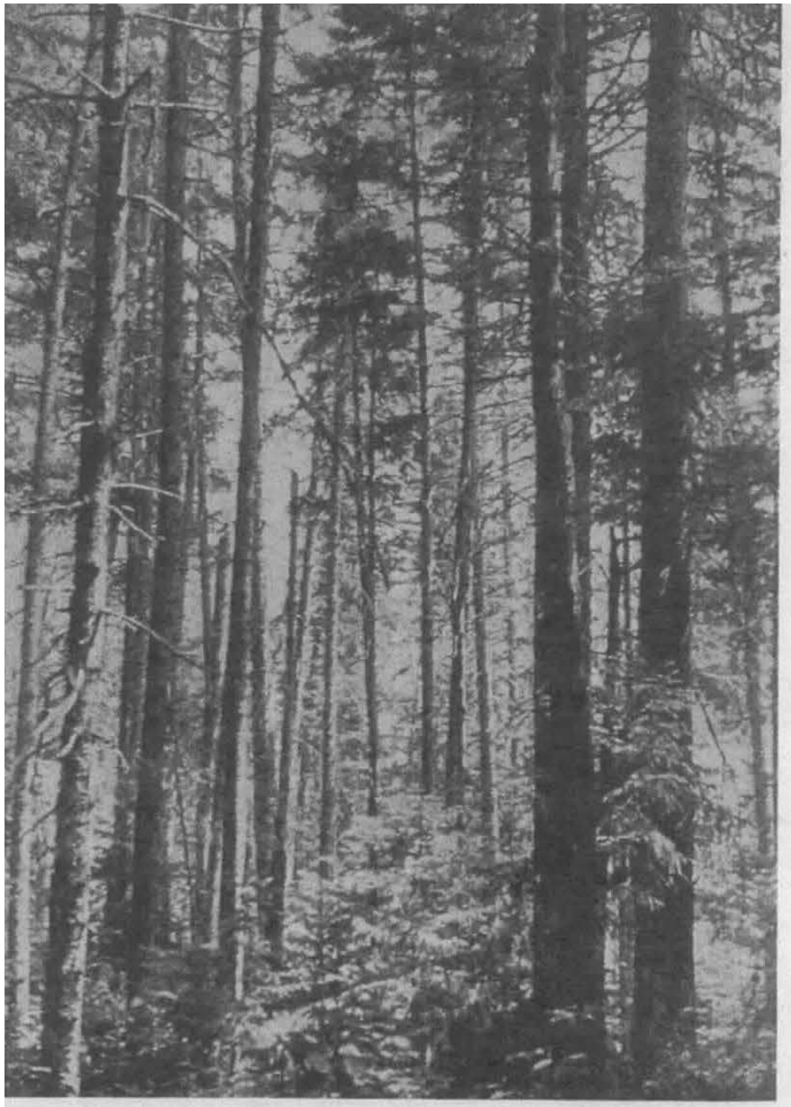

FIGURE 7. REPRESENTATIVE SPRUCE FLAT FOREST TYPE

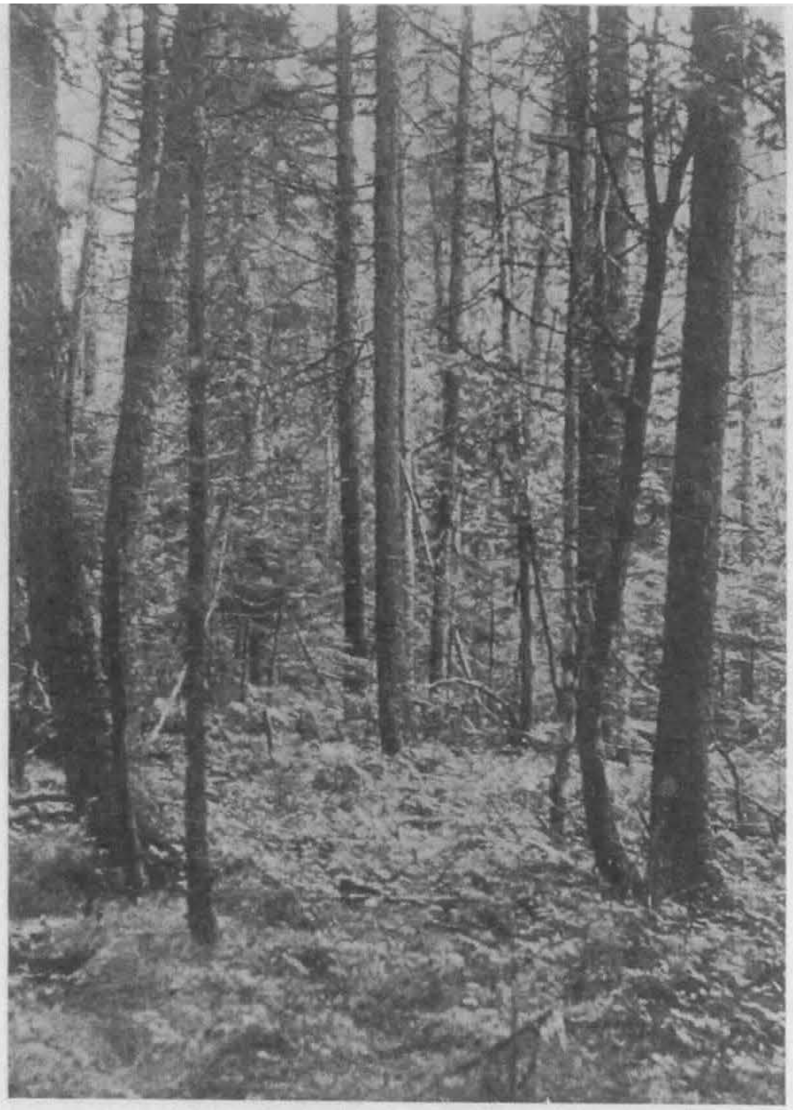

FIGURE 8. REPRESENTATIVE SPRUCE SWAMP FOREST TYPE

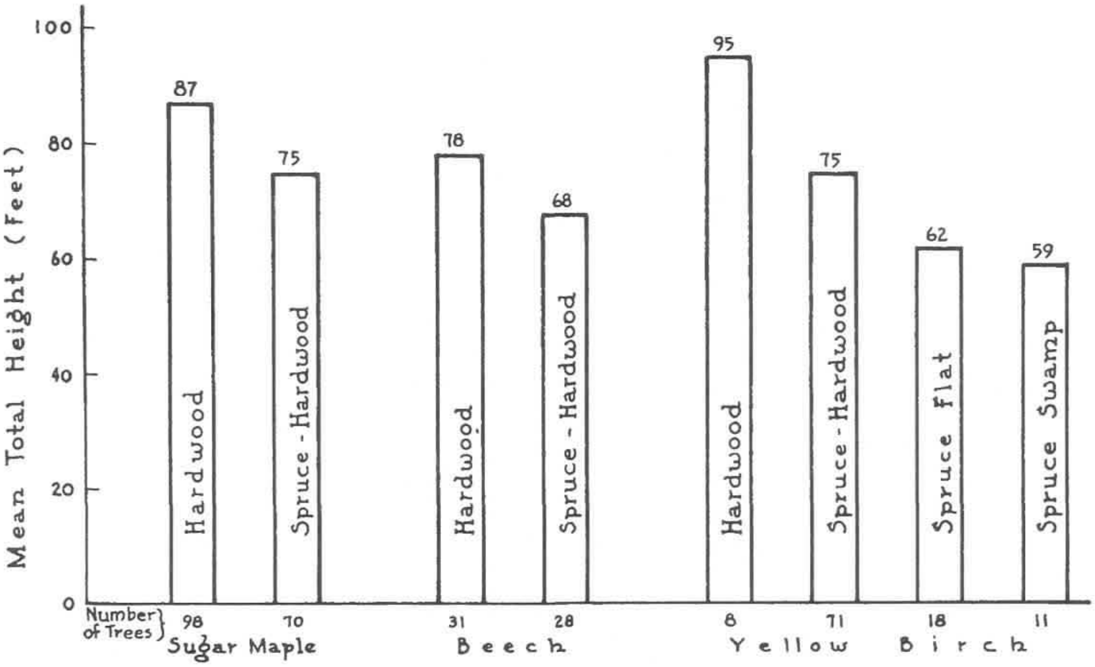

FIGURE 9. MEAN TOTAL HEIGHT OF DOMINANT AND CO-DOMINANT HARDWOODS BY SPECIES AND BY FOREST TYPES

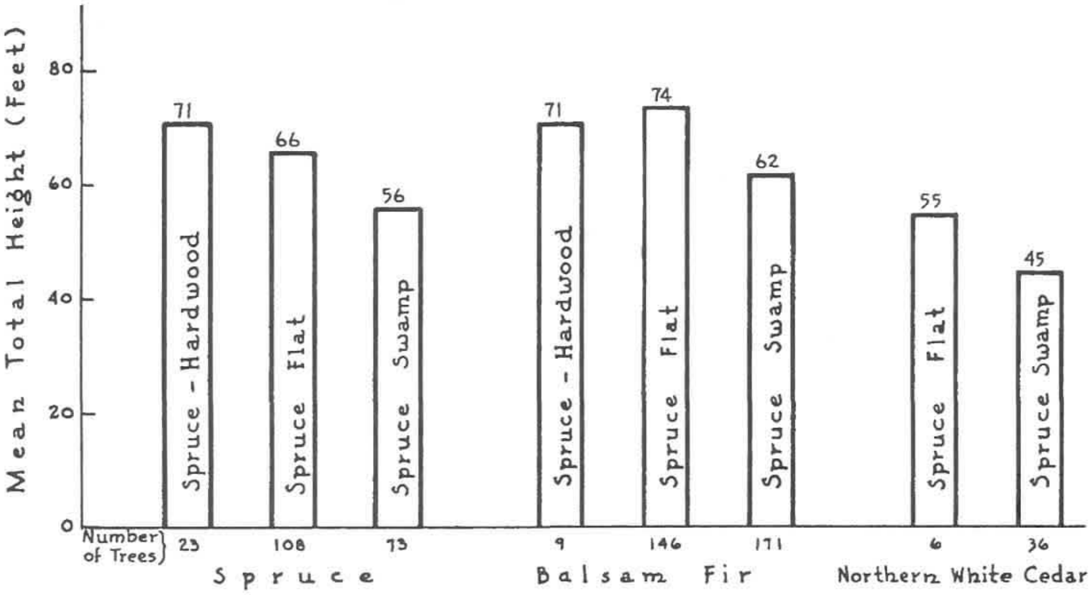

FIGURE 10. MEAN TOTAL HEIGHT OF DOMINANT AND CO-DOMINANT SOFTWOODS BY SPECIES AND BY FOREST TYPES

measurements would have increased the mean height on the spruce-hardwood type, data given by Zon (1914), based on the measurements of 683 balsam-fir trees, show average heights of 61, 55, and 48 feet at 100 years of age, for the hardwood slope (spruce-hardwood), the flat, and the swamp, respectively.

It can therefore be stated with fair assurance that, if one accepts height growth at maturity as a good index of site quality, then: (1) the hardwood type is the most favorable for sugar maple, beech, and yellow birch; (2) the spruce-hardwood type is the most favorable for spruce and balsam fir;

and (3) northern white cedar makes its best development on the spruce flat type. Based upon total height at maturity, the general-productivity level is therefore

hardwood > spruce-hardwood > spruce flat > spruce swamp

BASAL AREA

The basal area of all trees on each plot was determined by converting the d.b.h. measurements into their equivalent cross-sectional areas.

In the hardwood type, sugar maple accounted for more than one-half of the total basal area; in the spruce-hardwood type, yellow birch predominated; while balsam fir had the greatest basal area on both the spruce flat and the spruce swamp type.

The total basal areas for all species on all forest types (including trees 1 inch d.b.h. and over) are compared graphically in figure 11. The greatest total basal area exists on the spruce-hardwood type, followed closely by the spruce flat type and the hardwood type. The spruce swamp has the smallest basal area.

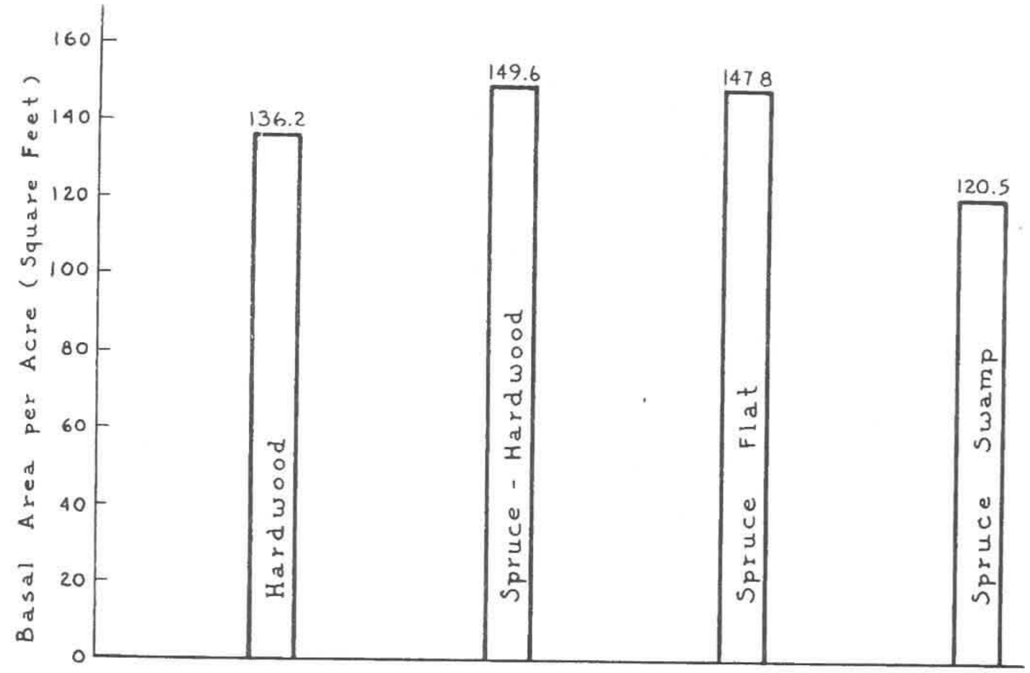

FIGURE 11. AVERAGE BASAL AREA IN SQUARE FEET PER ACRE BY FOREST TYPES (INCLUDING ALL TREES 1 INCH D. B. H. AND OVER)

It has just been shown that with total height as a site-quality index the relative order of productivity is:

hardwood > spruce-hardwood > spruce flat > spruce swamp

Other data which follow also support this hypothesis. On the contrary, basal area is the only factor calculated which does not bear out the same conclusions. Many other apparent inconsistencies have been reported, however, by Foster (1935), who concluded that the best sites do not always show the greatest basal area. It seems, therefore, that basal area alone is a poor indicator of site quality. This conclusion is borne out by European forest research.

SPECIFIC GRAVITY OF THE WOOD

It was suggested by Dr. J. Nelson Spaeth[16] that pounds of wood may prove to be a better criterion than cubic feet, for classifying sites. Dr. Spaeth's idea rested on the fact that stands of northern white pine frequently produce more cubic feet per acre per year than do the northern hardwoods on the same or even on an inferior site. The specific gravity of the pine is less than that of most hardwoods (Markwardt and Wilson, 1935). It was reasoned, therefore, that the less dense wood of greater volume may amount to fewer pounds of wood per acre per year.

With this hypothesis, the specific gravity of the increment borings from 440 softwood and 174 hardwood trees was determined separately for sapwood and for heartwood. The increment cores used in the determination of specific gravity fulfilled the following specifications: (1) they must have reached the tree's center or approximate center; (2) they must be free from defect; and (3) they must represent trees 100 years old or older, with the exception of balsam fir and the miscellaneous species,[17] for which 50 years was the minimum age.

The actual determination of the specific gravity of the increment borings involved: (1) measuring their volume when saturated with water, by immersion in a burette, and then checking this volume against the volume obtained by calculations based upon micrometer measurements; (2) weighing the cores after drying for 24 hours in an oven regulated at 100° to 105° C.; (3) dividing the oven-dry weight in grams by the water-saturated volume in cubic centimeters.

This technique is recommended by Koehler (1924), who stated:

> For many purposes it is more desirable to determine the volume of the wood, when fully saturated, since in this condition it may be submerged without coating it with paraffin. Furthermore, it will have reached an extreme condition which can easily be duplicated; while, if shrinkage has taken place, the results are more variable since wood shrinks differently with different methods of drying. The oven-dry weight is preferred since it also represents an extreme condition which can easily be duplicated.

The average specific gravity, by forest types, of sapwood and heartwood increment borings, is given in table 1 separately for each hardwood species; the comparable data for the softwood species are given in table 2. The average specific-gravity values obtained by combining sapwood and heartwood values in all the forest types are shown in table 3, in which, for comparison, the corresponding values given by the Forest Products Laboratory (Markwardt and Wilson, 1935) are presented also.

It is seen in table 3 that the writer's specific-gravity values average slightly higher than do those obtained by the Forest Products Laboratory. This discrepancy may be accounted for in two ways: (1) the increment borings were obtained at 4.5 feet above the ground, while the Laboratory's sample usually represented the top of the first 16-foot log, which is normally less dense (Koehler, 1924); (2) samples extracted with an increment borer are likely to be compressed, thereby reducing the volume of the cores and thus increasing the specific gravity. There is one factor, however, tending to compensate for these larger values: the figures taken from the Labora-

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[16] Formerly assistant professor of forestry at Cornell University; now head of the Department of Forestry at the University of Illinois, Urbana.

[17] Miscellaneous species included red maple, paper birch, tamarack, American elm, white ash, basswood, and eastern hemlock. With these species there were not enough individuals 100 years old or older to make an adequate sample.

TABLE 1. AVERAGE SPECIFIC GRAVITY, BY FOREST TYPES, OF SAPWOOD AND HEARTWOOD INCREMENT BORINGS FROM EACH HARDWOOD SPECIES

(Weight of wood oven-dry; volume of wood water-saturated)

Species	Forest type							
	Hardwood		Spruce-hardwood		Spruce flat		Spruce swamp	
	Specific gravity	Number of trees	Specific gravity	Number of trees	Specific gravity	Number of trees	Specific gravity	Number of trees
Sugar maple:								
Sapwood	0.61	34	0.61	31	...	...	...	...
Heartwood	0.58	34	0.62	31	...	...	...	...
Beech:								
Sapwood	0.59	16	0.59	13	...	...	...	...
Heartwood	0.59	16	0.61	13	...	...	...	...
Yellow birch:								
Sapwood	0.60	4	0.56	31	0.52	12	0.54	10
Heartwood	0.61	4	0.56	28	0.57	12	0.59	10
White ash:								
Sapwood	0.59	4	...	...	...	...	...	...
Heartwood	0.59	4	...	...	...	...	...	...
Basswood:								
Sapwood	0.33	5	...	...	...	...	...	...
Heartwood	...	...	...	...	...	...	...	...
American elm:								
Sapwood	0.44	2	...	...	...	...	...	...
Heartwood	0.48	2	...	...	...	...	...	...
Paper birch:								
Sapwood	...	...	...	...	0.50	1	0.51	1
Heartwood	...	...	...	...	...	...	0.51	1
Red maple:								
Sapwood	...	...	0.54	9	0.57	1	...	...
Heartwood	...	...	0.56	9	...	...	...	...

TABLE 2. AVERAGE SPECIFIC GRAVITY, BY FOREST TYPES, OF SAPWOOD AND HEARTWOOD INCREMENT BORINGS FROM EACH SOFTWOOD SPECIES

(Weight of wood oven-dry; volume of wood water-saturated)

Species	Forest type					
	Spruce-hardwood		Spruce flat		Spruce swamp	
	Specific gravity	Number of trees	Specific gravity	Number of trees	Specific gravity	Number of trees
Spruce:						
Sapwood	0.40	20	0.42	90	0.41	64
Heartwood	0.49	1	0.42	5	0.40	1
Balsam fir:						
Sapwood	0.32	4	0.33	113	0.34	113
Heartwood	0.31	2	0.27	3	0.32	1
Northern white cedar:						
Sapwood	...	...	...	...	0.22	10
Heartwood	...	...	...	...	0.33	9
Eastern hemlock:						
Sapwood	0.42	3	...	...	...	...
Heartwood	...	...	...	...	...	...
Tamarack:						
Sapwood	...	...	...	...	0.38	23
Heartwood	...	...	...	...	0.58	21

tory's determinations were based on green volume, which is usually less than the water-saturated volume used by the writer.

On comparing the specific gravity of each species (average of sapwood and heartwood) on different forest types, no consistent relationship is found to exist. Sugar maple and beech are both slightly heavier when growing

TABLE 3. SPECIFIC-GRAVITY COMPARISONS

Species	Increment borings*	Forest Products Laboratory†
	Specific gravity	
Sugar maple	0.60	0.56
Beech	0.60	0.56
White ash	0.59	0.55
Yellow birch	0.57	0.55
Red maple	0.56	0.49
Paper birch	0.51	0.48
Tamarack	0.48	0.49
American elm	0.46	0.46
Eastern hemlock	0.42	0.38
Spruce	0.41	0.38
Balsam fir	0.33	0.34
Basswood	0.33	0.32
Northern white cedar	0.27	0.29

*Specific gravity calculated from oven-dry weight and water-saturated volume.
†Specific gravity calculated from oven-dry weight and green volume.

on the spruce-hardwood type, while yellow birch is heavier on the hardwood type. Spruce produces heavier wood on the spruce flat, and balsam fir has a higher specific gravity when growing in the spruce swamp. None of the differences in specific gravity is greater than 0.06, and hence the differences may be due entirely to experimental error. This conclusion, in essence, agrees with the findings of Paul (1930), who noted no consistent change in specific gravity with site. Paul did find an increase in specific gravity, however, when proper silvicultural measures were applied.

VOLUME IN CUBIC FEET

The total volume in cubic feet per acre for each species, by forest types (table 4), was determined by field measurements of the diameter breast high and the total height, and then summarized from appropriate volume tables.[18] The total cubic feet for all species by forest types agrees with the original hypothesis that the productivity level is:

hardwood > spruce-hardwood > spruce flat > spruce swamp

The total volumes are 4430, 3402, 1734, and 1456 cubic feet, respectively, for this order of productivity. Thus it seems that total cubic feet per acre is a fair index of site quality.

Looking at the subject from the standpoint of forest management, the number of years to produce these volumes is extremely important. By counting all of the rings on the increment borings that had reached the center or approximate center of the tree, an average age for the dominant and the co-dominant trees was obtained for each forest type, as follows: hardwood, 134 years; spruce-hardwood, 147 years; spruce flat, 115 years; spruce swamp, 101 years.

The total existing volume per acre for all species was divided by the average age, to furnish the values shown graphically in figure 12. This also confirms the hypothetical productivity rating; that is, the hardwood

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[18] The following volume tables were used. From University of Minnesota Agricultural Experiment Station, Technical Bulletin 39, 1926: for sugar maple, table 53; for beech, table 27; for yellow birch, table 33; for red maple, table 49; for basswood, table 24; for white ash, table 9; for American elm, table 40; for paper birch, table 29; for northern white cedar, table 35; for balsam fir, table 18; for tamarack, table 92. From New York State College of Forestry, Bulletin 14: for red spruce, table 56; for hemlock, table 50.

TABLE 4. EXISTING VOLUME AND WEIGHT (OVEN-DRY) OF WOOD FOR THE AVERAGE ACRE, BY SPECIES AND BY FOREST TYPES
(Dominant and co-dominant trees only)

Species	Forest type							
	Hardwood		Spruce-hardwood		Spruce flat		Spruce swamp	
	Cubic feet	Pounds	Cubic feet	Pounds	Cubic feet	Pounds	Cubic feet	Pounds
Sugar maple	2,920	109,383	1,313	50,826	.....	.....	.....	......
Beech	433	15,947	230	8,616	.....	.....	.....	......
Yellow birch	256	9,590	1,434	50,133	110	3,708	112	3,916
White ash	74	2,725	.....	......	.....	.....	.....	......
Basswood	431	8,611	.....	......	.....	.....	.....	......
American elm	316	9,076	.....	......	.....	.....	.....	......
Paper birch	.....	......	.....	......	.....	.....	3	96
Red maple	.....	......	114	3,915	23	818	.....	......
Spruce	.....	......	189	5,192	808	21,186	338	8,440
Balsam fir	.....	......	63	1,259	759	14,216	744	15,326
Northern white cedar	.....	......	.....	......	34	594	150	2,622
Eastern hemlock	.....	......	59	1,547	.....	.....	.....	......
Tamarack	.....	......	.....	......	.....	.....	109	3,267
Total	4,430	155,332	3,402	121,488	1,734	40,522	1,456	33,667

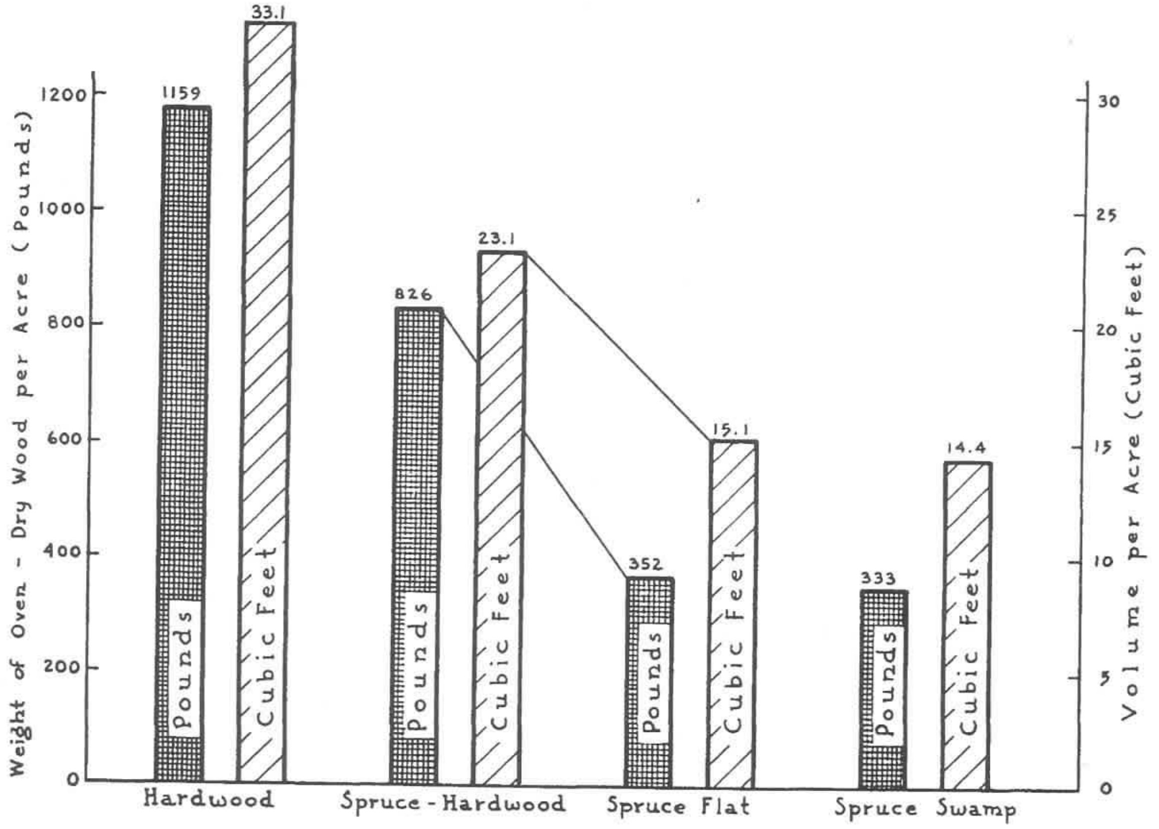

FIGURE 12. MEAN ANNUAL INCREMENT, IN POUNDS OF OVEN-DRY WOOD AND IN CUBIC FEET PER ACRE, OF ALL SPECIES BY FOREST TYPES

type produces more wood volume in cubic feet per acre per year than does the spruce-hardwood type. Comparing spruce flat and spruce swamp, the

POUNDS OF OVEN-DRY WOOD

The weight of oven-dry wood per acre (table 4) was obtained by (1) multiplying the average specific gravity for sapwood and heartwood by the number of pounds of water per cubic foot (62.43), thus determining the weight of a cubic foot of wood for each species, and (2) multiplying the weight of a cubic foot by the total number of cubic feet in a species, which gave the total number of pounds of oven-dry wood. The mean annual increment in pounds of dry wood per acre (figure 12) was calculated by dividing the total number of pounds given in table 4 by the average age of the dominant and the co-dominant trees.

The mean annual increment in pounds of oven-dry wood and in cubic feet per acre is shown graphically in figure 12. The actual figures, as well as the ratios (based on the hardwood type as 100), are as follows:

	Increment per acre per year			
Forest type	Cubic feet	Ratio	Pounds	Ratio
Hardwood	33.1	100	1,159	100
Spruce-hardwood	23.1	**70**	826	**71**
Spruce flat	15.1	**46**	352	**30**
Spruce swamp	14.4	44	333	29

It is interesting, from the standpoint of comparing the number of cubic feet and of pounds of wood per acre, to see which gives the better index of site quality. Using the hardwood forest type as 100, the spruce-hardwood type in each case is essentially the same for both the pounds and the cubic feet. The greatest difference appears when comparing the predominantly hardwood forest of the spruce-hardwood type with the almost pure softwood forest of the spruce flat type. A drop in ratio from 71 to 30 for the number of pounds of wood on the spruce flat type is much greater than the corresponding ratio decrease in cubic feet (70 to 46). The conclusion can therefore be drawn that, in this study, the number of pounds of oven-dry wood produced per acre per year is a better index of site quality, when comparing hardwood and softwood stands, than is the volume in cubic feet for the same period.

The Society of American Foresters (1923) proposed that *cubic feet per acre per year* be adopted to replace *site quality I, II,* and so on. From figure 12 it appears, as stated above, that pounds of wood per acre per year may be a better index of site quality, especially when comparing hardwood and softwood stands. Another argument for adopting this proposal is a statement by Paul (1930): "... the specific gravity of the wood is used as a measure of the mechanical properties of the species ... ." It may be deduced, therefore, that if two sites produce the same volume of wood in the same period, the one with the heavier wood is considered the better site. It is particularly important to have wood of high specific gravity (and therefore with great strength) when dealing with species such as ash and hickory, since their major use is for tool handles. The use of sugar maple for furniture and flooring also requires that the wood be dense, hard, and strong.

CUMULATIVE RADIAL GROWTH

The increment borings taken from 330 hardwood and 536 softwood trees[19] at breast height were analyzed in the following manner: (1) each core was soaked for at least two minutes in tap water; (2) every tenth annual ring was marked with a soft-lead pencil; (3) the decades were measured to the nearest hundredth-inch, beginning at the cambium.

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[19] The increment borings analyzed were limited to those taken from the dominant and the co-dominant trees

The cumulative-radial-growth data, by species and by forest types, was then summarized by starting at the center of the cores and adding each successive radial increment to the previous total (figures 13 to 18). The radial growth was measured inside the bark at breast height. To convert to d.b.h. ouside the bark, one should multiply the ordinate values by 2 and add the two bark thicknesses.

The cumulative radial growth of sugar maple on the hardwood and spruce-hardwood forest types is shown in figure 13. During the first 150 years the conditions for radial growth were superior in the spruce-hardwood type, but for the past 80 years the trees on the hardwood type have been definitely the faster-growing. This phenomenon may be explained in several ways: (1) the light intensity in the spruce-hardwood forest, being higher than in the hardwood type (figure 27, page 27), may favor faster radial growth of the saplings; (2) the mean heights of the trees are less in the spruce-hardwood type, and hence the trees may become dominant at an earlier age and therefore increase in radial growth sooner; and/or (3) after a tree has become dominant in the hardwood type, it may have a more favorable moisture and nutrient supply, and consequently surpass the cumulative growth on the spruce-hardwood type.

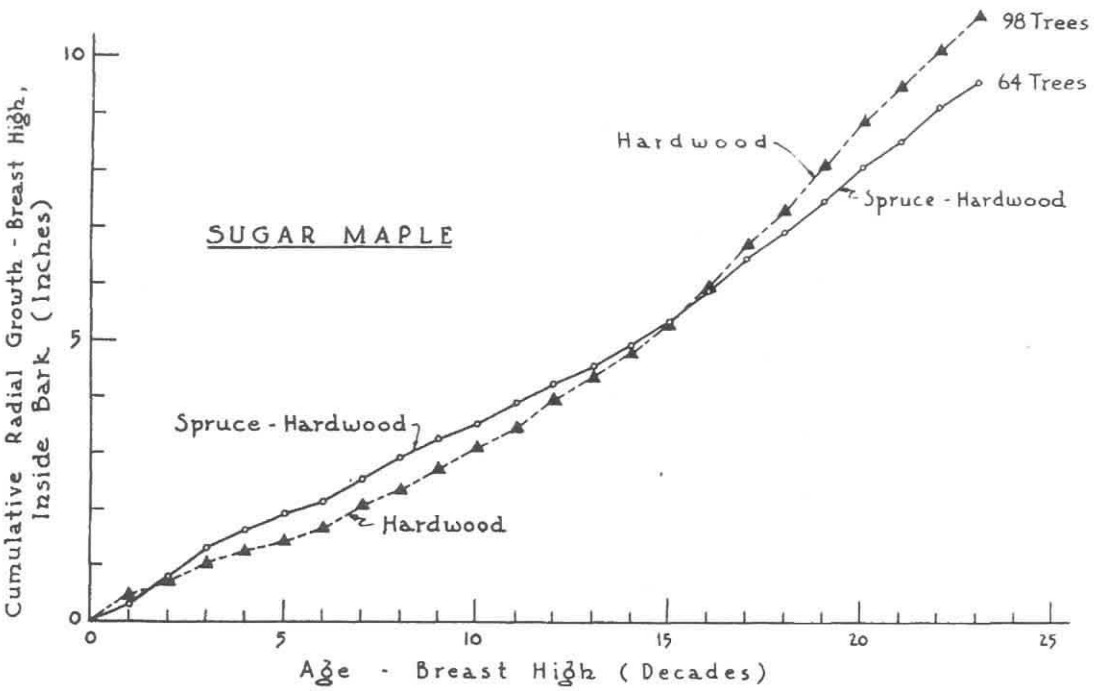

FIGURE 13. CUMULATIVE RADIAL GROWTH OF SUGAR MAPLE, BREAST HIGH, INSIDE BARK, IN THE HARDWOOD AND SPRUCE-HARDWOOD FOREST TYPES

The cumulative radial growth of beech on the hardwood and spruce-hardwood forest types is shown in figure 14. It is seen that there was practically no difference in growth on the two sites. These data confirm the conclusions reached by R. H. Westveld (1933), based on a comparable study in northern Michigan.

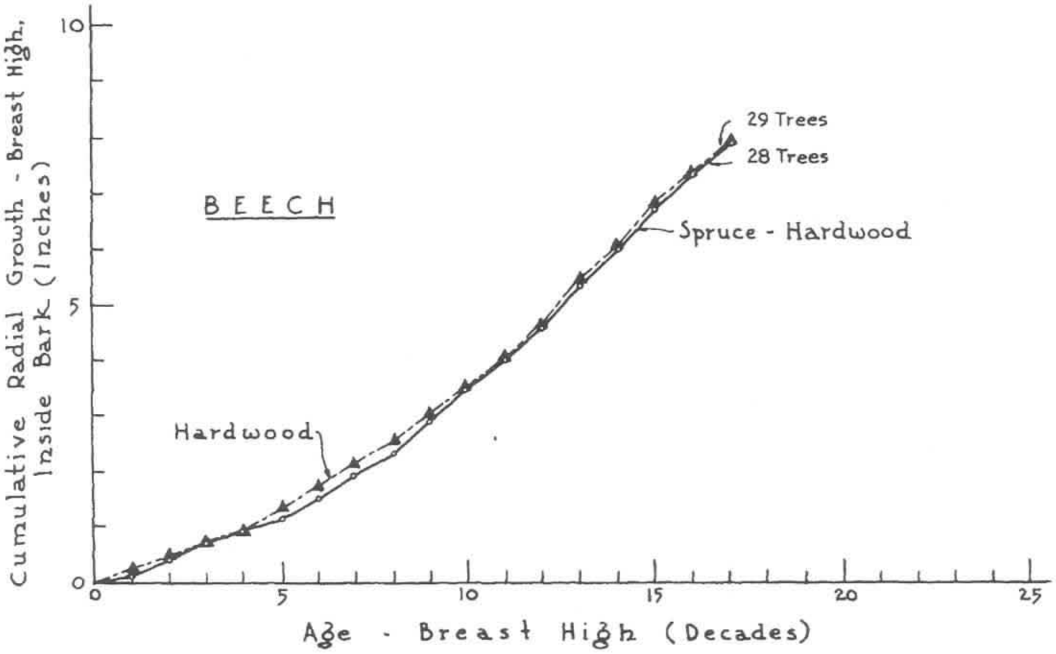

FIGURE 14. CUMULATIVE RADIAL GROWTH OF BEECH, BREAST HIGH, INSIDE BARK, IN THE HARDWOOD AND SPRUCE-HARDWOOD FOREST TYPES

The cumulative radial growth of yellow birch on all four of the forest types studied is shown in figure 15. The best radial growth was made in spruce-hardwood stands, the next best in hardwood, and the poorest in the spruce flat and the spruce swamp. These data are difficult of explanation. The small yellow-birch seedlings apparently cannot withstand severe competition. Neither do they seem to require a fertile soil for proper development; rotten stumps and barren rocks frequently support large thrifty individuals.

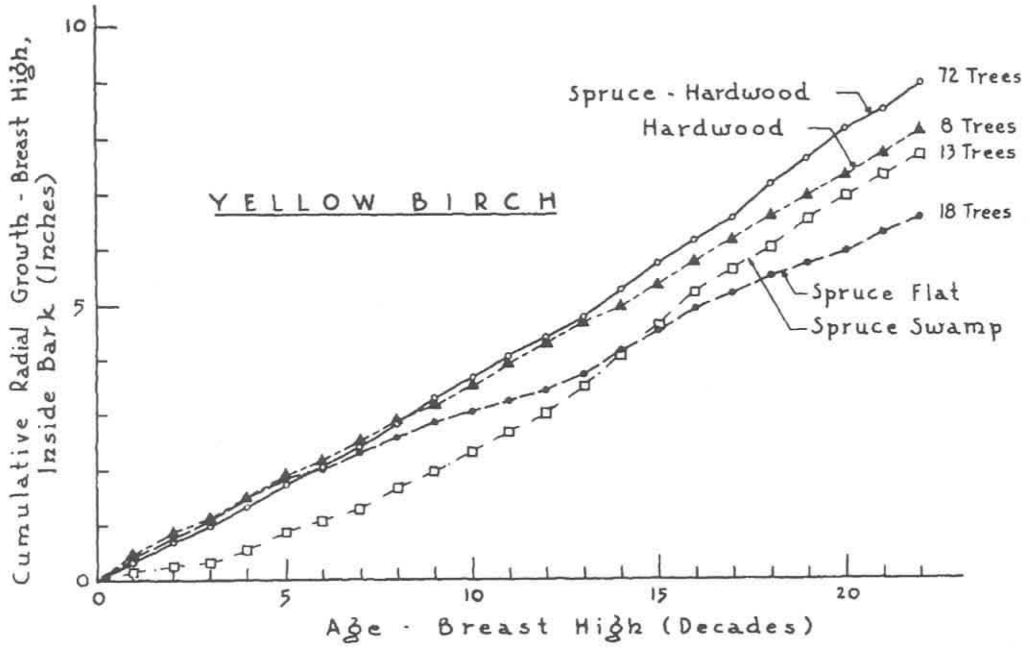

FIGURE 15. CUMULATIVE RADIAL GROWTH OF YELLOW BIRCH, BREAST HIGH, INSIDE BARK, IN THE HARDWOOD, SPRUCE-HARDWOOD, SPRUCE FLAT, AND SPRUCE SWAMP FOREST TYPES

The radial growth of spruce (figure 16) was most rapid in the spruce flat forest type, next in the spruce-hardwood, and least in the spruce swamp. No dominant trees were found on the hardwood type. It is apparent that aggressive species such as sugar maple tend to suppress and overtop the spruce in its growth toward dominance. This may be the explanation for the inferior radial growth of spruce in the spruce-hardwood forest type. The only hardwood of any abundance in the spruce flat type is yellow birch, which does not seem to be as aggressive a species as sugar maple. The spruce swamp type supported very slow growth, owing, no doubt, to the high water table.

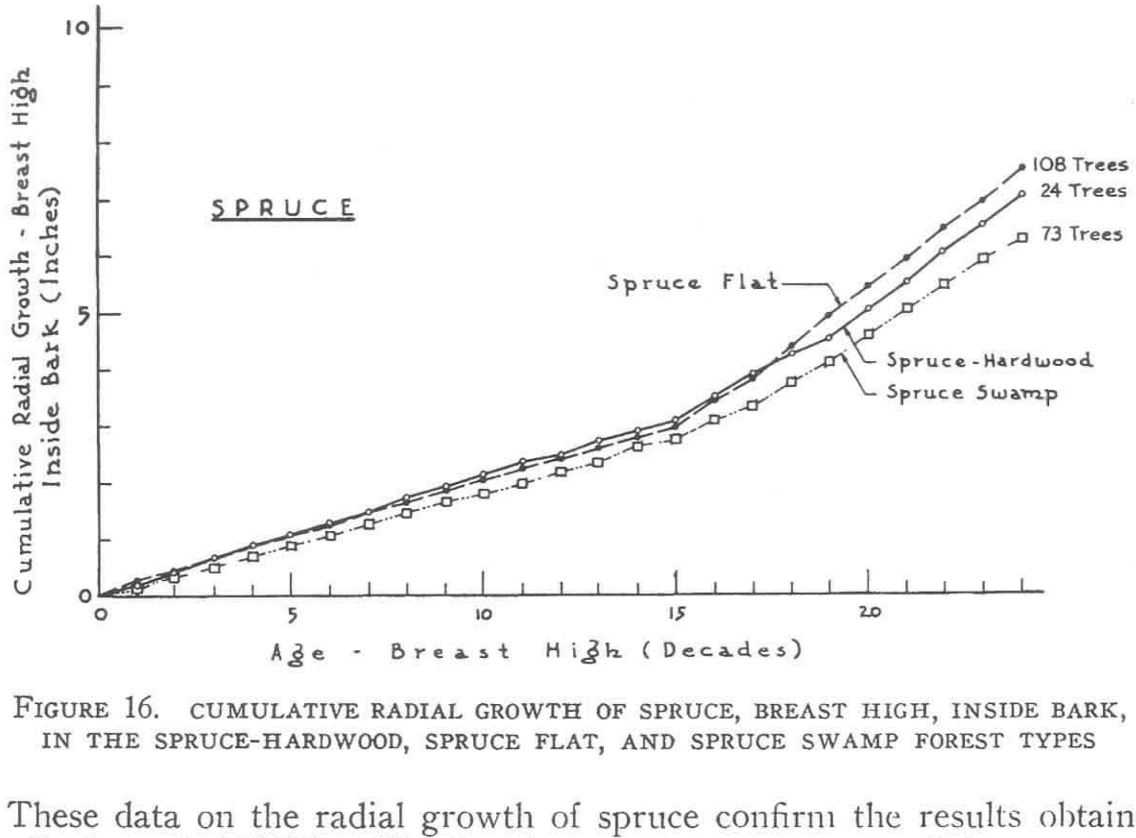

FIGURE 16. CUMULATIVE RADIAL GROWTH OF SPRUCE, BREAST HIGH, INSIDE BARK, IN THE SPRUCE-HARDWOOD, SPRUCE FLAT, AND SPRUCE SWAMP FOREST TYPES

These data on the radial growth of spruce confirm the results obtained by Recknagel (1922). He found greater current annual increment of spruce on the spruce flat than on the hardwood forest type,[20] the values being 3.11 per cent and 2.76 per cent, respectively.

Although balsam fir (figure 17) represented a greater proportion of the number of dominant and co-dominant trees on the spruce swamp than on the spruce flat, its radial growth in the spruce swamp was inferior. This may possibly be explained on the basis that the swamp environment contained less soil oxygen because of a permanent high water table.

The radial growth of northern white cedar (figure 18) was faster in the spruce flat type than in the spruce swamp. The entire radial-growth curves form almost parallel lines approximately one-half inch in radius apart. The same explanation for slower growth in the spruce swamp will probably hold true here as in the case of balsam fir and spruce.

From the standpoint of using a tree species whose radial growth is the most sensitive to site, sugar maple appears to top the list in this study.

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[20] The "hardwood" of Recknagel's study is the same forest type as the spruce-hardwood type used here.

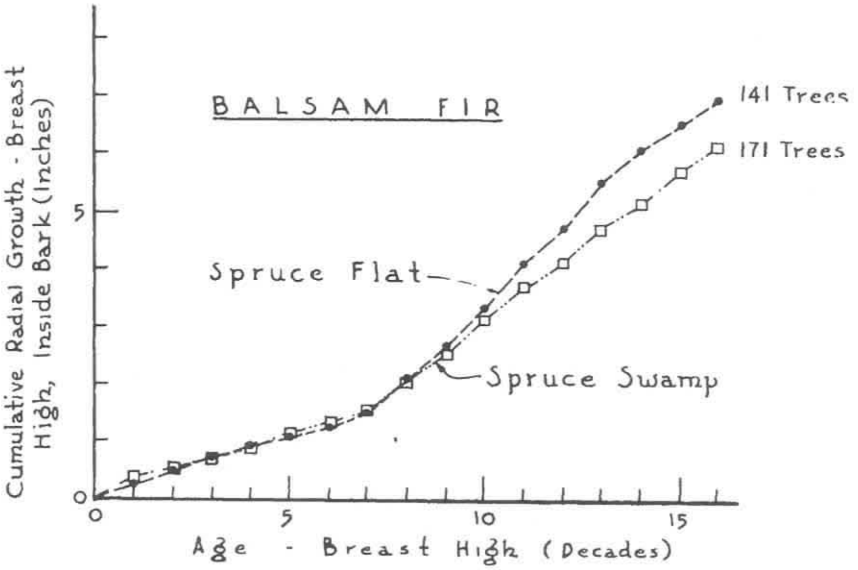

FIGURE 17. CUMULATIVE RADIAL GROWTH OF BALSAM FIR, BREAST HIGH, INSIDE BARK, IN THE SPRUCE FLAT AND SPRUCE SWAMP FOREST TYPES

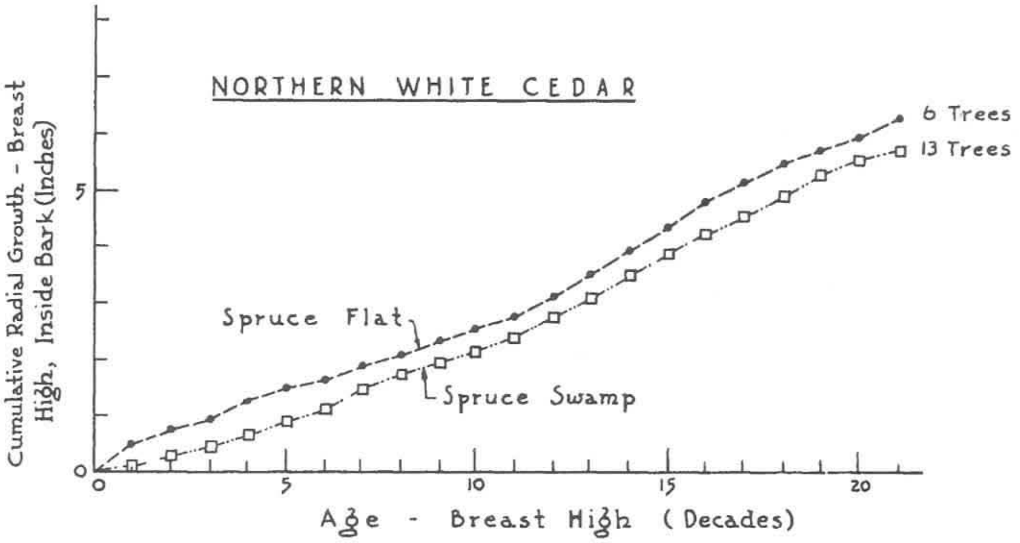

FIGURE 18. CUMULATIVE RADIAL GROWTH OF NORTHERN WHITE CEDAR, BREAST HIGH, INSIDE BARK, IN THE SPRUCE FLAT AND SPRUCE SWAMP FOREST TYPES

White ash, basswood, and American elm, by their mere presence, are probably better indicators of site quality, but their distribution in the Adirondacks is definitely restricted. Beech is the poorest indicator of all.

Photographs of representative increment cores are shown in figures 19 to 22. These cores were selected because they closely approximate the actual mean values for each species.

PLANT-INDICATOR TYPES

The ground-cover types (figures 23 to 26) were determined by making a quantitative enumeration of the species present on five 1-square-foot samples on each of the 16 acres. Also, Dr. Carl C. Heimburger[21] visited

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[21] Heimburger (1934) studied the ground-cover species in the Adirondacks, and gave to the plant associations names derived from their indicator species.

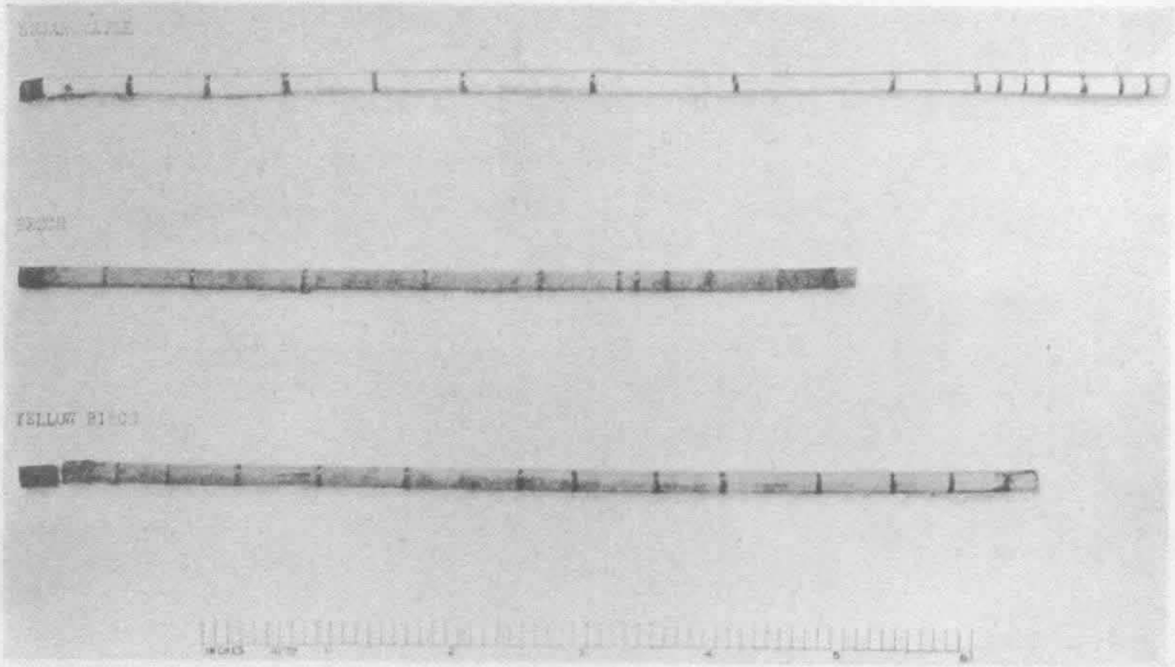

FIGURE 19. MEAN SAMPLE CORES FROM THE HARDWOOD FOREST TYPE
The lines delimit decades

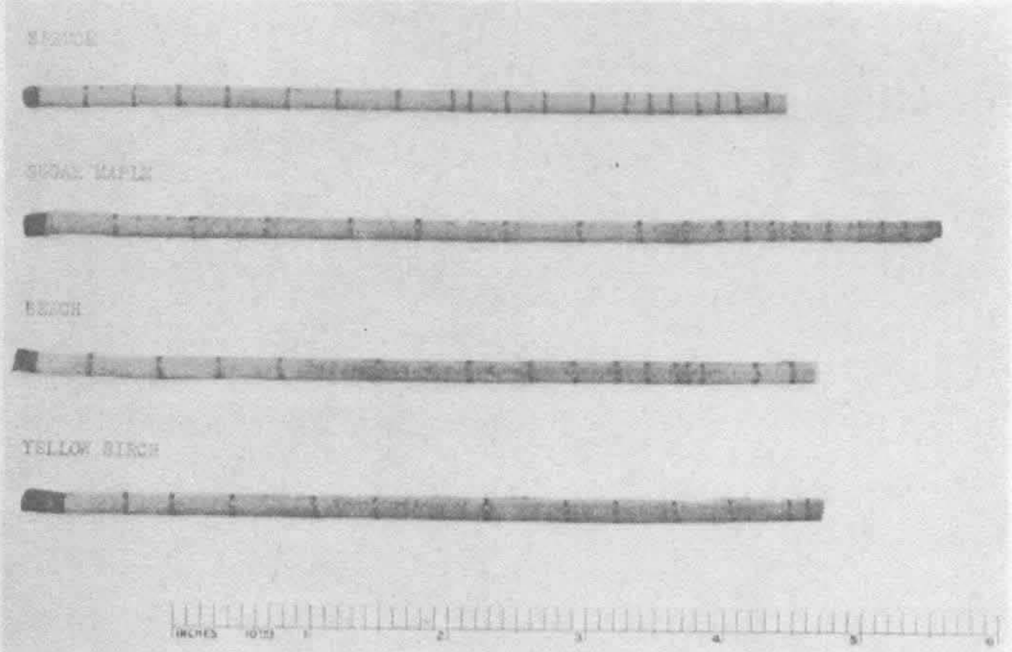

FIGURE 20. MEAN SAMPLE CORES FROM THE SPRUCE-HARDWOOD FOREST TYPE
The lines delimit decades

the plots. The results of the actual tally of the plants agreed with the personal opinion of Dr. Heimburger and are presented below:

Forest type	Ground-vegetation type
Hardwood	Poor Arisaema type
Spruce-hardwood	Average Viburnum-Oxalis type
Spruce flat	Poor Oxalis-Cornus type
Spruce swamp	Rich Sphagnum-*Carex trisperma* type

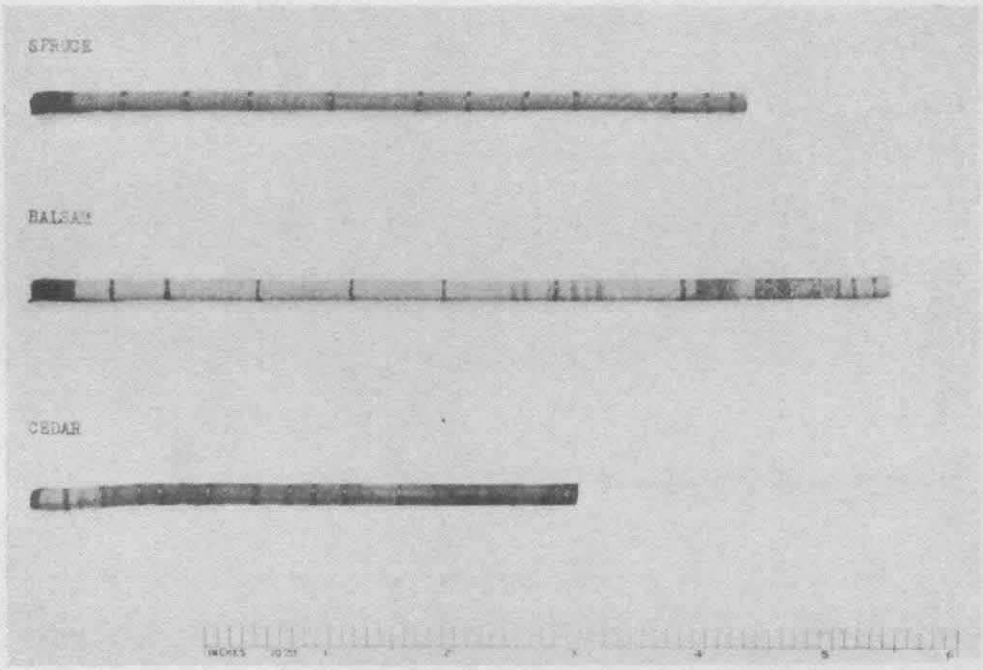

FIGURE 21. MEAN SAMPLE CORES FROM THE SPRUCE FLAT FOREST TYPE
The lines delimit decades

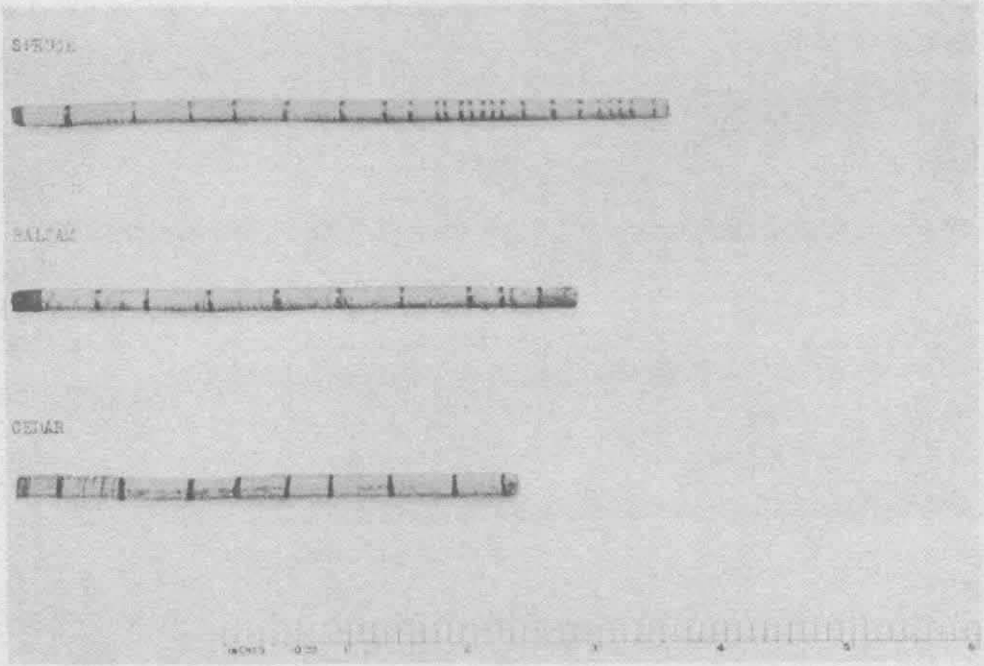

FIGURE 22. MEAN SAMPLE CORES FROM THE SPRUCE SWAMP FOREST TYPE
The lines delimit decades

LIGHT INTENSITY

The light intensity in foot-candles was measured by a Weston sunlight meter, model 603. Each acre plot was staked at 25 regular intervals (see plot technique, page 8), and the maximum sunlight readings were taken on the forest floor and at 3 and 6 feet above the forest floor. These recordings were made between the hours of 10 a.m. and 2 p.m. (Eastern daylight-saving time) and on as cloudless a day as was possible. Both before

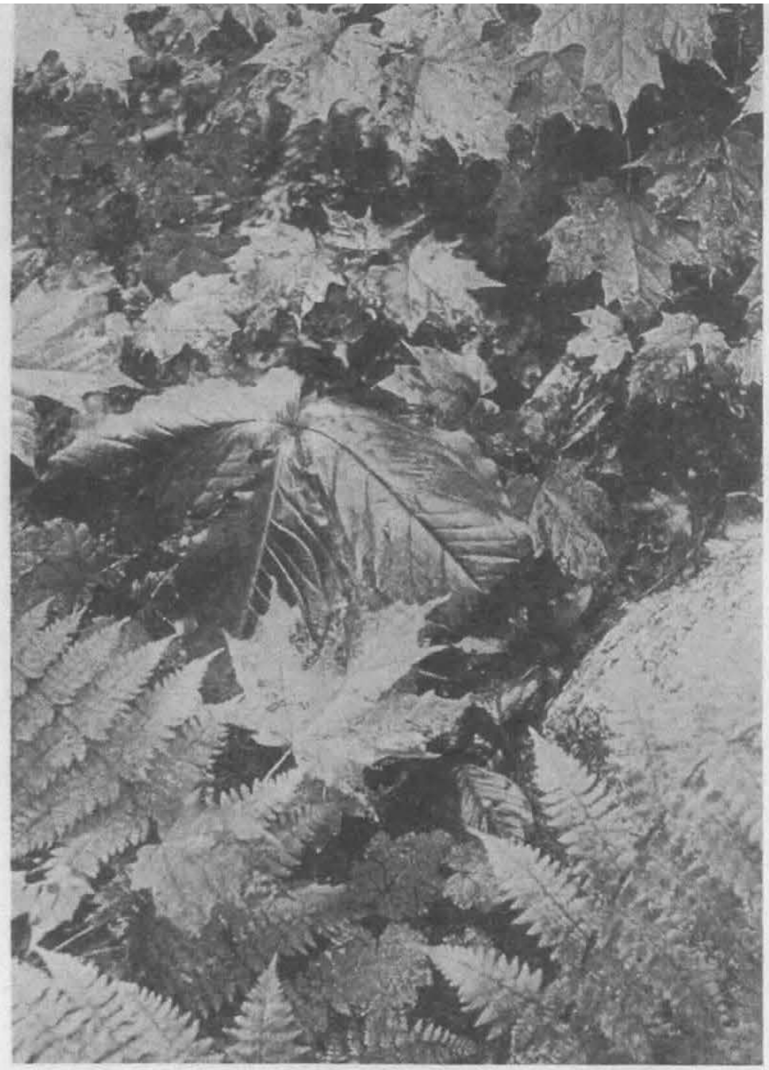

FIGURE 23. REPRESENTATIVE ARISAEMA PLANT-INDICATOR TYPE (HARDWOOD FOREST TYPE)

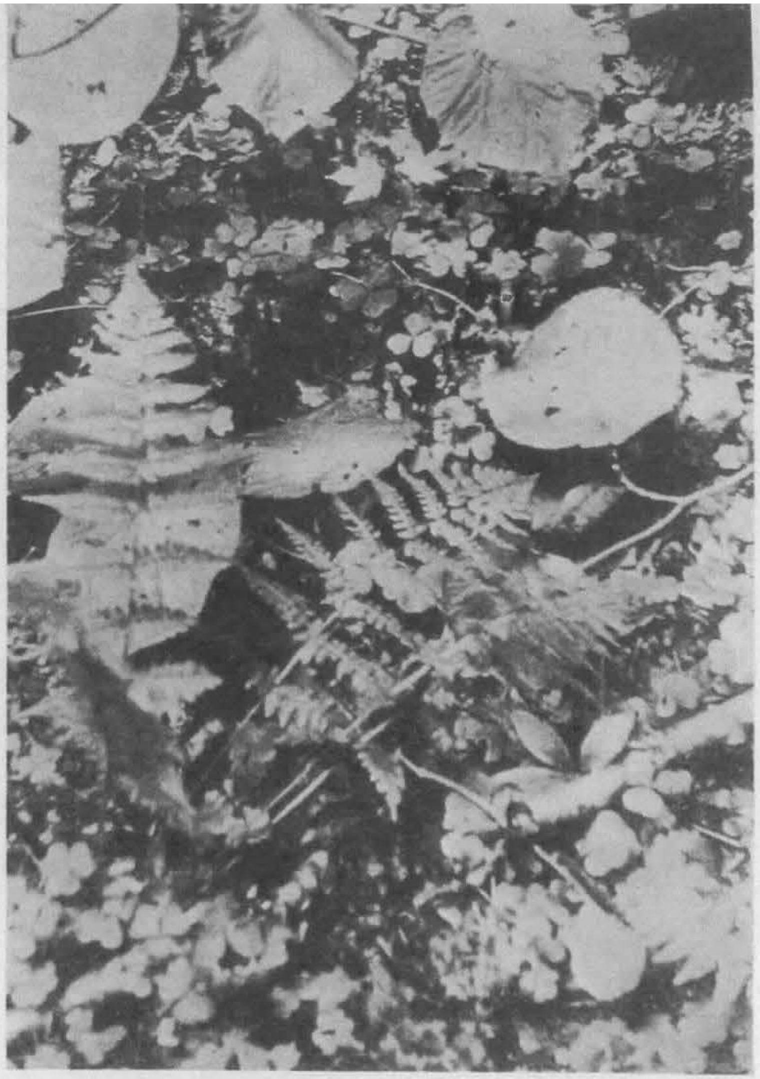

FIGURE 24. REPRESENTATIVE VIBURNUM-OXALIS PLANT-INDICATOR TYPE (SPRUCE-HARDWOOD FOREST TYPE)

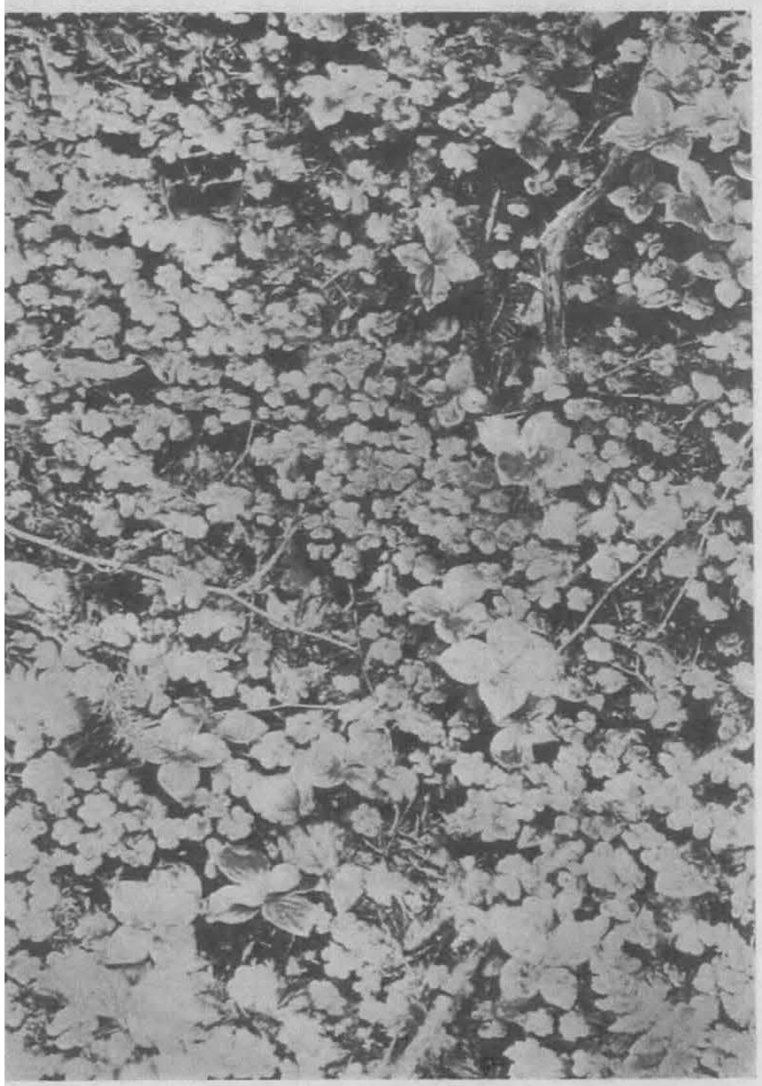

FIGURE 25. REPRESENTATIVE OXALIS-CORNUS PLANT-INDICATOR TYPE (SPRUCE FLAT FOREST TYPE)

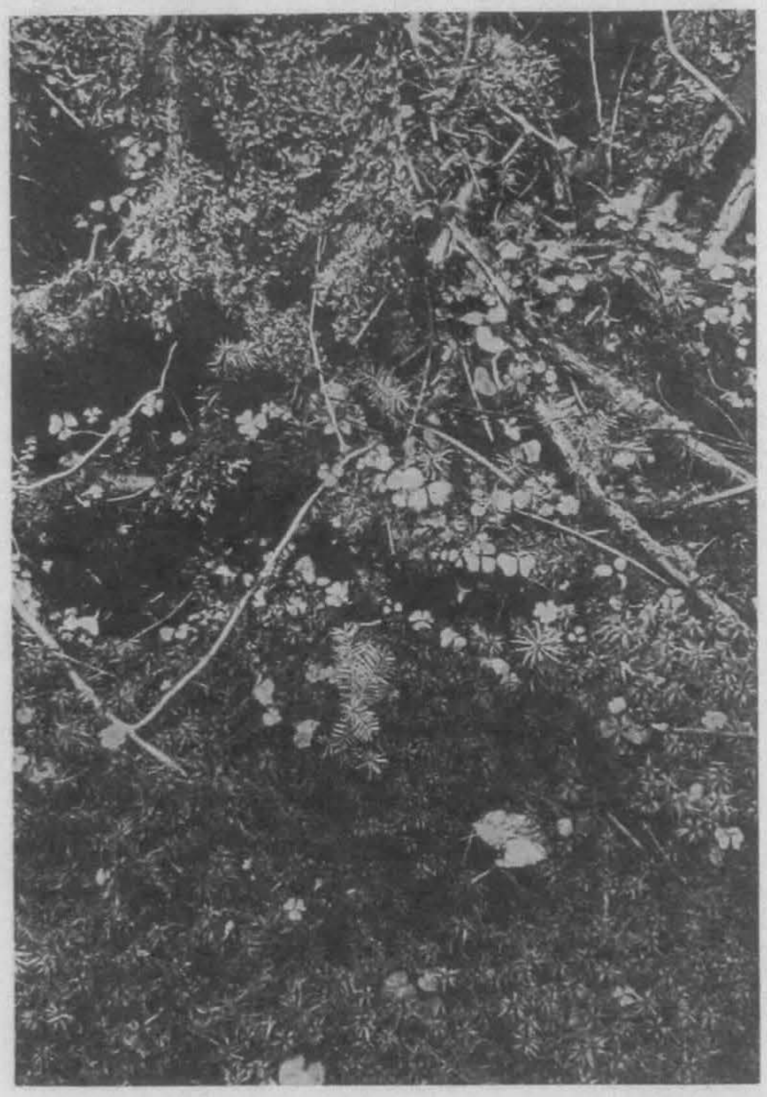

FIGURE 26. REPRESENTATIVE SPHAGNUM-*Carex trisperma* PLANT-INDICATOR TYPE (SPRUCE SWAMP FOREST TYPE)

and after taking the light readings in the forest, full-sunlight measurements were made in a near-by clearing. An attempt was made to measure the light in the forest only during a full-sunlight reading of 10,000 foot-candles. This aim was not entirely fulfilled, however, and for three plots the full-sunlight readings were 7800, 8400, and 8500 foot-candles, respectively. For the remaining thirteen plots the full-sunlight intensity was above 9400 foot-candles.

The mean light intensities at 0, 3, and 6 feet above the forest floor are shown in figure 27 for the four forest types. It is obvious that some of the mean values by individual plots overlap from one forest type to another, but it is obvious also that the average sunlight recorded by forest types is inversely proportional to the general productivity level. In order to make all light data more comparable, all light readings are expressed in relation to a full-sunlight reading of 10,000 foot-candles. The supposition is that an increase in full sunlight brings about a corresponding increase in the light striking the ground cover.

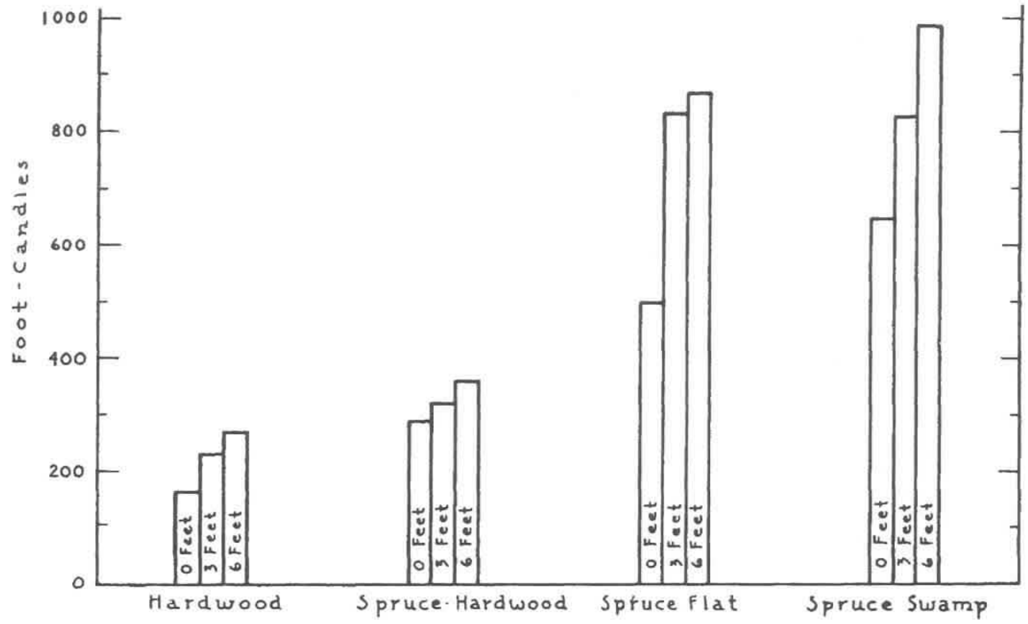

FIGURE 27. MEAN LIGHT INTENSITY AT 0, 3, AND 6 FEET ABOVE THE FOREST FLOOR, BY FOREST TYPES

A glance at figure 27 shows: (1) that the light intensity varies directly with the height above the forest floor, up to the 6-foot limit measured; and (2) that the light filtering through the forest canopy in the various forest stands is in this order:

spruce swamp > spruce flat > spruce-hardwood > hardwood

There is some doubt whether the *mean* light intensity gives a true basis for comparison, inasmuch as one small opening in the canopy would greatly increase the *mean* of a series of readings. With this thought in mind the *median* was determined, since this is not influenced by extremes. For the sake of brevity the data are not given here. However, the comparative values obtained for the different forest types were in exactly the same order as is shown in figure 27, in which the *mean* values are plotted. The only discrepancy occurred, not *between* forest types, but rather *within* a forest type: the *median* light intensity at the 6-foot level on the spruce swamp was less than that at the 3-foot level.

Assuming that the stands are fully stocked, it can therefore be concluded from this study that light intensity in the forest is inversely proportional to site quality.

ANALYSIS OF SOIL CHARACTERISTICS

COMPOSITE SOIL PROFILE

A schematic representation of the soil profiles that have developed under the various forest types is shown in figure 28. The variations in the thickness of each horizon include the extremes encountered in charting approximately 120 square feet of soil-pit wall.[22]

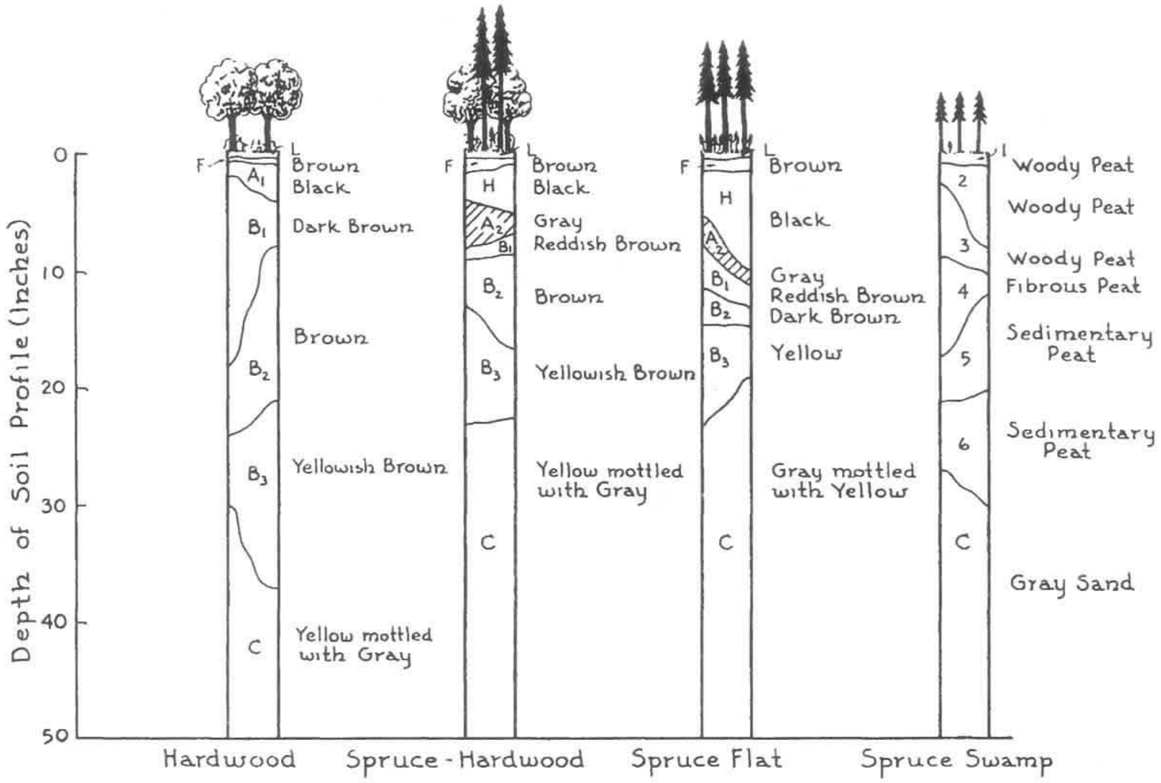

FIGURE 28. SCHEMATIC GRAPH OF COMPOSITE SOIL PROFILES, BY FOREST TYPES

Essex is the soil-series name that has been assigned to the hardwood profile (figure 29), and *Beckett* is the name applied to the strongly podzolized soil of the spruce-hardwood type (figure 30).[23] So far as the writer knows, the soils on neither the spruce-flat nor the spruce-swamp areas have received official soil-series names.

According to the system of humus-layer classification reported by Heiberg (1937), the hardwood soil-humus type was a *fine mull*, the spruce-hardwood a *granular mor*, and the spruce flat a *greasy mor*.

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[22] On each acre plot a soil pit was dug, 10 feet by 3 feet in extent and as deep as tree roots were encountered. The average of four of such pits on each forest type was used in graphing the schematic profiles shown in figure 28.

[23] According to the soil classification proposed by the United States Department of Agriculture (1938), Essex and Beckett would be grouped as Brown Podzolic and Podzol, respectively.

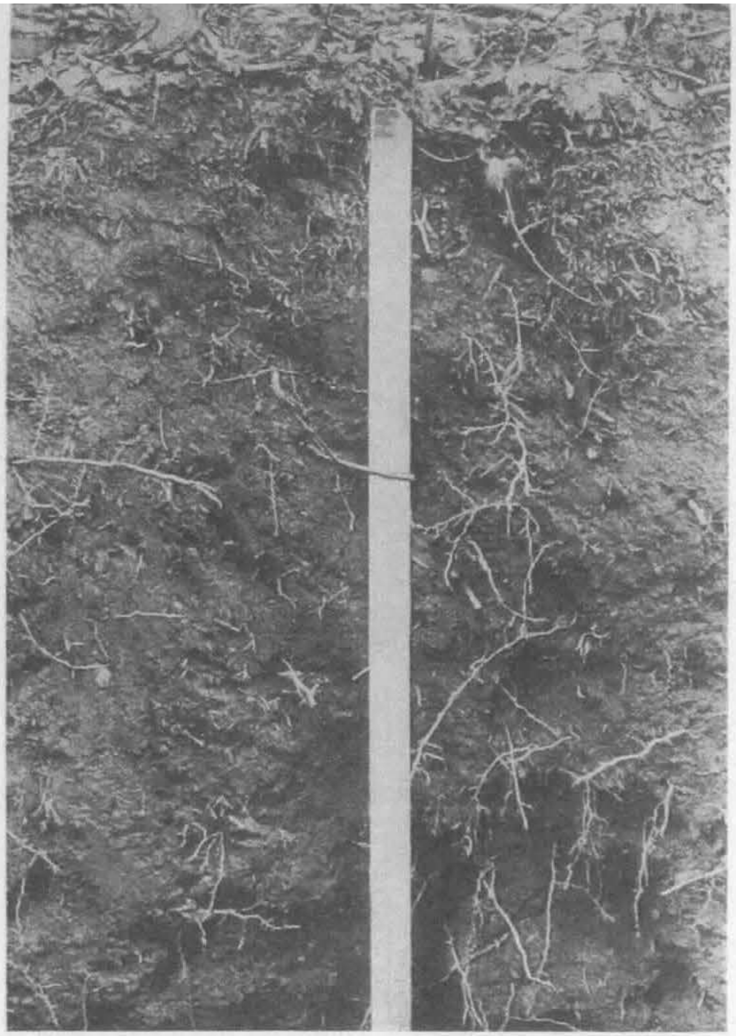

FIGURE 29. TYPICAL SOIL PROFILE UNDER THE HARDWOOD FOREST TYPE
Essex soil series; a Brown Podzolic soil

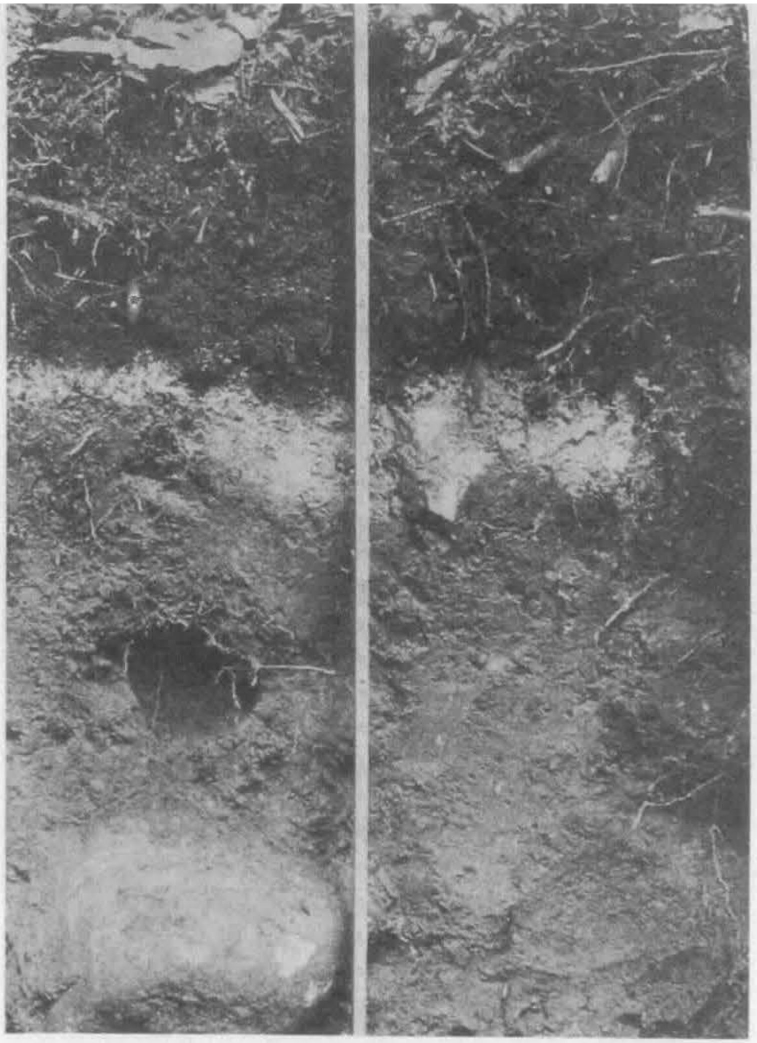

FIGURE 30. TYPICAL SOIL PROFILE UNDER THE SPRUCE-HARDWOOD FOREST TYPE, SHOWING THE THICK H LAYER AND THE GRAY, STRONGLY PODZOLIZED, A_2 HORIZON
Beckett soil series; a true Podzol soil

On soils of similar geological origin, it can be reasoned that the gray A_2 horizon in the spruce flat type should be thicker than the corresponding layer in the spruce-hardwood type because of the greater renewal of bases to the surface of the soil through hardwood leaf-fall[24] (Kellogg, 1936). Under the conditions of this study, however, the influence of parent material retarded the dominant expression of vegetation. In the spruce flat type, where the parent material was influenced by soda-lime feldspar, the A_2 horizon was very thin.

The fact is worthy of mention that both the Essex and the Beckett series, on the hardwood and spruce-hardwood types, respectively, have compact C horizons that retard both root and water penetration.

ELEVATION AND EXPOSURE

The highest point on any of the plots included in this study is 2014 feet; the absolute lowest point is 1620 feet.

It seems particularly significant that all of the hardwood plots have a southerly exposure, while all of the spruce-hardwood plots have a northerly exposure. This fact, if generally true throughout the Adirondacks, may account for the presence of basswood, American elm, and white ash in the warmer exposure of the hardwood sites.

DEGREE OF STONINESS

The degree of stoniness of the soil is represented in table 5 by two separate methods. The pounds of rocks[25] per cubic foot of soil-pit volume are

TABLE 5. WEIGHT AND VOLUME OF ROCKS, BY KINDS, IN THE VARIOUS ACRE PLOTS

Forest type	Plot	Kind of rock	Weight of rocks (pounds)	Volume of pit (cubic feet)	Weight of rocks per cubic foot of pit (pounds)	Volume of pit occupied by rocks* (per cent)
Spruce-hardwood	A	Adirondack gneiss	1,955	....	17.4	....
		Anorthosite	150	....	1.3	....
		Miscellaneous	23	....	0.2	....
		Total	2,128	112.5	18.9	11.5
	F	Adirondack gneiss	2,680	....	47.3	....
		Anorthosite	5	....	0.1	....
		Miscellaneous	.....	....	.....	....
		Total	2,685	56.7	47.4	28.7
	G	Adirondack gneiss	765	....	14.8	....
		Anorthosite	10	....	0.2	....
		Miscellaneous	495	....	9.6	....
		Total	1,270	51.7	24.6	14.9
	H	Adirondack gneiss	1,600	....	30.0	....
		Anorthosite	6	....	0.1	....
		Miscellaneous	6	....	0.1	....
		Total	1,612	53.3	30.2	18.4
	Total for spruce-hardwood		7,695	274.2	28.1	17.1

*Calculated by assuming a uniform specific gravity of 2.65.

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[24] The hardwoods in the Adirondacks have a higher content of calcium in the leaves than do most of the conifers (Chandler, 1939 b).

[25] The larger rocks removed in the excavation of the soil pits were weighed and the volume of the pit was determined by measurements. Rocks smaller than about one-half pound were not weighed.

TABLE 5 *(concluded)*

Forest type	Plot	Kind of rock	Weight of rocks (pounds)	Volume of pit (cubic feet)	Weight of rocks per cubic foot of pit (pounds)	Volume of pit occupied by rocks* (per cent)
Hardwood	I	Adirondack gneiss	1,100	....	21.7	....
		Anorthosite	146	....	2.9	....
		Miscellaneous	.....	....	.....	....
		Total	1,246	50.6	24.6	15.0
	J	Adirondack gneiss	1,650	....	33.0	....
		Anorthosite	80	....	1.6	....
		Miscellaneous	6	....	0.1	....
		Total	1,736	50.0	34.7	21.1
	K	Adirondack gneiss	1,344	....	17.9	....
		Anorthosite	7	....	0.1	....
		Miscellaneous	10	....	0.1	....
		Total	1,361	75.0	18.1	11.0
	L	Adirondack gneiss	744	....	12.7	....
		Anorthosite	91	....	1.6	....
		Miscellaneous	.....	....	.....	....
		Total	835	58.7	14.3	8.6
	Total for hardwood		5,178	234.3	22.1	13.4
Spruce flat	M	Adirondack gneiss	30	....	0.6	....
		Anorthosite	790	....	16.3	....
		Miscellaneous	65	....	1.3	....
		Total	885	48.6	18.2	11.1
	N	Adirondack gneiss	30	....	0.6	....
		Anorthosite	608	....	11.4	....
		Miscellaneous	.....	....	.....	....
		Total	638	53.3	12.0	7.3
	O	Adirondack gneiss	50	....	1.1	....
		Anorthosite	531	....	11.9	....
		Miscellaneous	.....	....	.....	....
		Total	581	44.7	13.0	7.9
	P	Adirondack gneiss	10	....	0.2	....
		Anorthosite	308	....	6.8	....
		Miscellaneous	.....	....	.....	....
		Total	318	45.1	7.0	4.3
	Total for spruce flat		2,422	191.7	12.6	7.7
Spruce swamp	(No rocks in peat layers)					

*Calculated by assuming a uniform specific gravity of 2.65.

shown in column 6, and the percentage of the soil-pit volume occupied by rocks is shown in column 7. The spruce-hardwood plots contained the most rocks, with 28.1 pounds per cubic foot of original soil volume; next in order was the soil in the hardwood type, having 22.1 pounds, followed by the soil in the spruce flat type, with 12.6 pounds. The spruce swamp soil had no rocks in the organic layers, although the sandy C horizon contained large quantities of anorthosite.

Comparing the volume of the soil pit occupied by rocks,[26] the average values are 17.1, 13.4, and 7.7 per cent, respectively, for the soils in the spruce-hardwood, the hardwood, and the spruce flat forest types.

In the hardwood and spruce-hardwood types, the rocks are predominantly Adirondack gneiss; in the spruce types, anorthosite is the country rock.

The greater stoniness of the soil supporting the spruce-hardwood type may possibly be a factor contributing toward the inferior productivity of that type. The difference between this soil and the soil under the hardwood forest is small, however, and it is doubtful whether the rocks play any important part in this connection.

MECHANICAL ANALYSIS

The percentage of coarse sand, fine sand, silt, and clay, was determined by a modification of the Bouyoucos (1936) hydrometer method. The modifications consisted of: (1) changing the conventional reading time as calculated from Stokes' law, so as to be able to plot a complete curve and to read from it the percentage of the various soil separates according to the classification of the International Society of Soil Science (Atterberg); (2) applying a correction coefficient for the elevation of the hydrometer in suspension, as given by Wintermyer, Willis, and Thoreen (1931: 201, figure 3, graph B).

The percentages of the various soil separates by horizons, averaged by forest types, are given in table 6.[27] The greatest amount of clay in any one horizon is 4.4 per cent, in the B_2 horizon of the spruce-hardwood type; the least amount is 1 per cent, in the C_1 horizon of the spruce flat type. The significance of the table is that it shows practically no difference in mechanical analysis between the forest types, particularly in the finer soil fractions. There is a tendency for the spruce-hardwood type to average slightly higher in silt and clay than does the hardwood type. This is some-

TABLE 6. MECHANICAL ANALYSIS OF THE SOIL HORIZONS, BY FOREST TYPES (International classification)

Forest type	Soil horizon	Coarse sand (per cent)	Fine sand (per cent)	Silt (per cent)	Clay (per cent)
Hardwood	A_1	41.5	42.1	13.6	2.8
	B_1	51.7	32.8	12.5	3.0
	B_2	39.7	41.6	15.3	3.4
	B_3	59.5	25.5	11.8	3.2
	C_1	71.6	15.2	10.6	2.6
Spruce-hardwood	A_1	48.6	30.9	17.0	3.5
	B_1	36.1	44.3	15.7	3.9
	B_2	50.0	29.1	16.5	4.4
	B_3	56.2	22.2	18.6	3.0
	C_1	70.3	20.6	7.4	1.7
Spruce flat	A_1	33.6	37.7	25.2	3.5
	B_1	30.4	52.3	14.3	3.0
	B_2	72.0	18.0	7.0	3.0
	B_3	47.0	37.5	11.8	3.7
	C_1	82.7	7.7	8.6	1.0

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[26] To convert pounds of rocks into volume, a uniform specific gravity of 2.65 was assumed.

[27] The values for the hardwood forest type are averages of plots I, J, K, and L; those for the spruce-hardwood type are averages of plots A, F, G, and H; the percentages representing the spruce flat type came from plot M only.

what surprising, since in the field identification the soil under the hardwood type was classified as a loam and that in the spruce-hardwood type as a sandy loam. The probable explanation lies in the fact that, in the hardwood type, organic matter has been incorporated deeper into the mineral layers and around the soil grains, so that the soil imparts a silty feel when it is rubbed between the fingers.

SOIL ACIDITY (pH)

The hydrogen-ion concentration (pH) of the various soil horizons was determined potentiometrically with a glass electrode. The soil samples were collected in August and September of 1938, air-dried, and passed through a 2-mm sieve, and the pH was determined on a 1 to 2.5 soil-water suspension.

The results of the pH determinations are shown in table 7. The highest pH recorded is 5.77, for the L horizon of plot K; the lowest is 3.12, for the H horizon of plot N. It is of interest to note that the C_1 horizon varies the least of all the horizons in its hydrogen-ion concentration.

TABLE 7. SOIL ACIDITY (pH) OF THE SOIL HORIZONS, BY PLOTS AND BY FOREST TYPES

Soil horizon	Hardwood				Spruce-hardwood				Spruce flat			
	Plot I	Plot J	Plot K	Plot L	Plot A	Plot F	Plot G	Plot H	Plot M	Plot N	Plot O	Plot P
L	5.21	5.35	5.77	5.29	5.16	4.96	5.12	4.85	....	.. .	....	....
F	5.19	5.26	5.73	4.94	4.85	4.68	4.68	5.02	3.84	3.60	3.77	4.43
H	....	....	....	....	3.43	3.51	3.48	3.70	3.26	3.12	3.48	3.92
A_1	4.24	4.33	5.38	4.33	....	....	....	....	....	...	..	....
A_2	....	....	....	....	3.74	3.90	3.99	3.99	3.60	3.65	3.87	4.41
B_1	4.40	4.97	5.18	4.96	3.92	4.31	4.19	4.41	3.90	3.97	4.33	4.84
B_2	5.02	5.14	5.18	5.04	4.57	4.82	4.79	4.73	4.55	4.58	4.70	5.12
B_3	5.16	5.35	5.29	5.12	4.82	5.09	5.16	5.35	4.97	5.23	5.16	5.33
C_1	5.21	5.51	5.45	5.26	5.06	5.12	4.77	5.26	5.16	5.23	5.35	5.36

	Spruce swamp			
	Plot Q	Plot R	Plot S	Plot T
1, Woody	4.31	3.99	4.58	3.92
2, Woody	4.58	4.24	4.63	3.79
3, Woody	5.01	4.55	4.90	3.97
4, Fibrous	5.14	4.33	5.21	4.01
5, Sedimentary	....	4.85	5.24	4.14
6, Sedimentary	....	5.12	....	4.38
C_1	5.14	4.31	5.62	....

The following distribution of pH values for all horizons will help to further analyze and explain the data:

pH range	Hardwood	Spruce-hardwood	Spruce flat	Spruce swamp
	Frequency			
3.00–3.99	0	9	12	4
4.00–4.99	7	14	8	13
5.00–5.99	21	9	8	7

The pH values thus appear to be highest on the hardwood forest type and lowest on the spruce flat type. This cannot be explained on the basis of genetic inheritance from the parent material,[28] but it can be accounted for on the basis of higher calcium content of the foliage of the trees (Chandler, 1939 b). The soil profile with the highest pH supported an average basal area of 22.9 square feet per acre of white ash, American elm, and basswood combined, all of which are species with a high calcium leaf-content. In contrast, the most acid soil was the spruce flat type, which contained mostly coniferous trees of low calcium leaf-content.

ANALYSIS OF ROOT DISTRIBUTION

ROOT CHARTS

In each acre plot selected for study, a soil pit was dug which measured 10 feet long, about 3 feet wide, and as deep as tree roots were encountered. The location of the pits within the acre plots was determined in each case by the proximity to particular forest trees. For both the hardwood and the spruce-hardwood forest type, the pits were located approximately equidistant from a dominant or co-dominant sugar maple, beech, and yellow birch; for the spruce flat and the spruce swamp type, spruce, balsam fir, and yellow birch served as a guide.

One wall of each soil pit was scraped clean and marked off with vertical and horizontal guide strings 1 foot apart. The roots were recorded on graph paper by the appropriate symbols, in five diameter classes. Representative root charts are shown in figures 31 to 34. The various symbols on the charts represent approximate root diameters as follows: small dots, less than 0.05 inch; open circles, 0.05 to 0.10 inch; large solid dots, 0.10 to 0.20 inch; crosses, 0.20 to 0.50 inch; open squares, 0.50 to 1.0 inch. Larger roots are drawn to scale. The cross-hatched areas represent rocks, and the kinds are designated by letters as follows: A, anorthosite; G, Adirondack gneiss.

SUMMARY BY SOIL HORIZONS

A summary of the root distributions as found in this study, by rock-free soil horizons and by forest types, is presented graphically in figures 35 and 36. As is seen in figures 31 and 35, in the hardwood type the total number of roots, as well as the number of small roots, decreased with depth from the surface downward. This conclusion is in accord with Lutz, Ely, and Little (1937), who studied the distribution of roots of northern white pine at Keene, New Hampshire. In the spruce-hardwood type, however, a different condition obtained. Under this type, the strongly leached A_2 horizon was apparently an unsatisfactory medium for root growth, as is evidenced by the small number of roots in this layer (figures 32 and 35). The H layer above, as well as the B_1 horizon below, contained a greater number of roots than did the A_2 horizon. The assumption that the smaller number of roots is due to an infertile soil is borne out by Turner (1936), who found the fewest shortleaf-pine roots in the poorest soil.

The distribution of roots by soil horizons in the spruce flat forest type

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[28] The parent material of the two most acid profiles was anorthosite, which contained more calcium than did the Adirondack gneiss parent material found under the two least acid forest types, the hardwood and the spruce-hardwood.

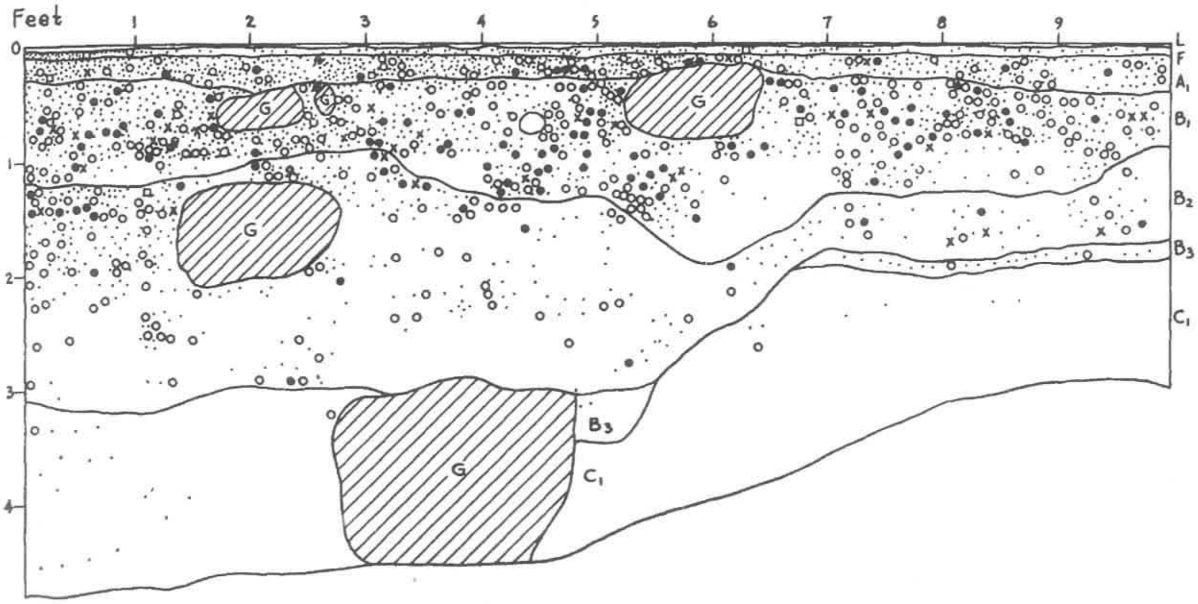

Figure 31. tree-root distribution on a typical hardwood site (plot K)

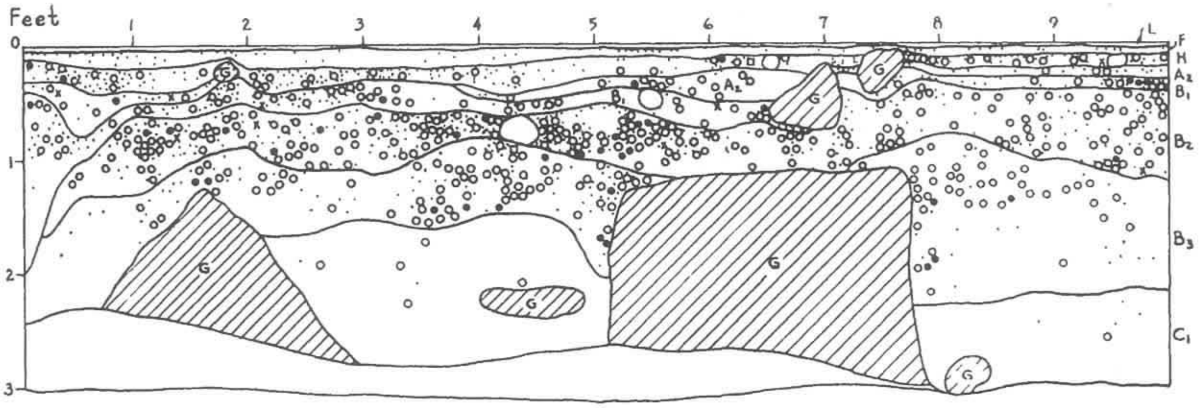

Figure 32. tree-root distribution on a typical spruce-hardwood site (plot H)

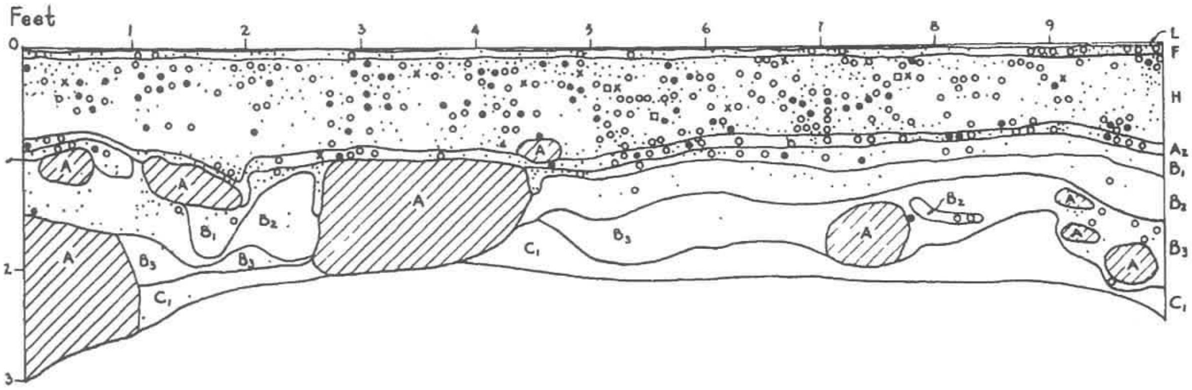

Figure 33. tree-root distribution on a typical spruce flat site (plot M)

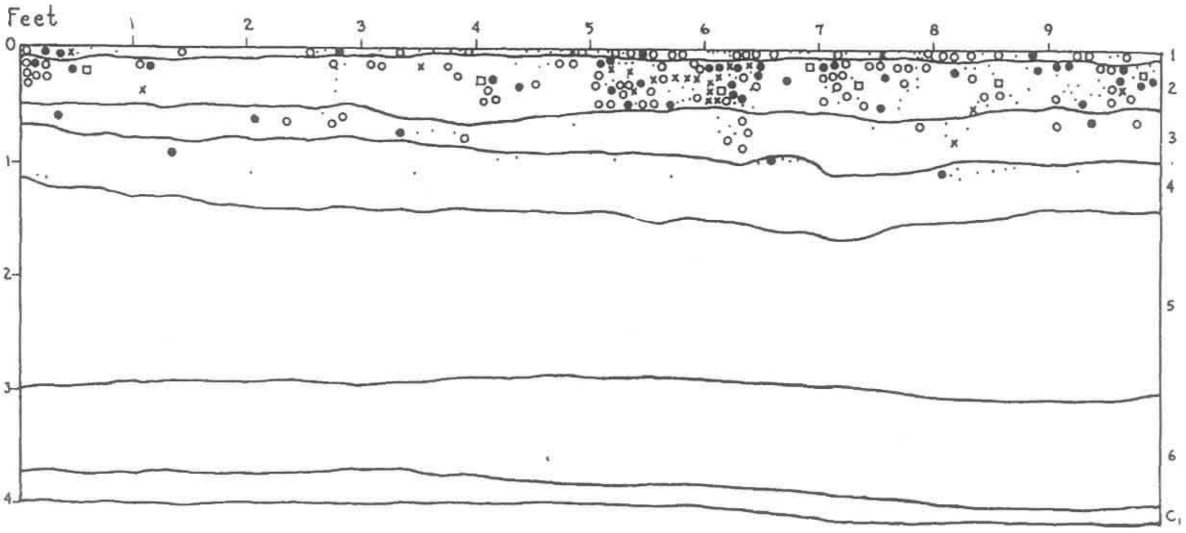

FIGURE 34. TREE-ROOT DISTRIBUTION ON A TYPICAL SPRUCE SWAMP SITE (PLOT R)

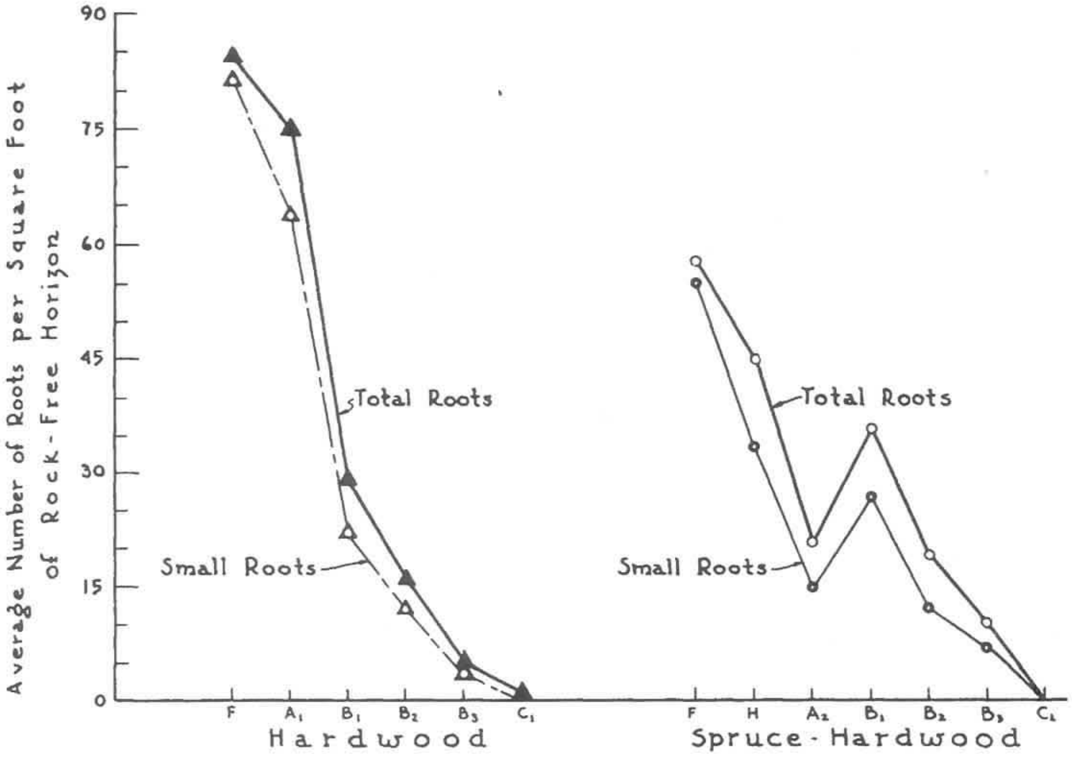

FIGURE 35. NUMERICAL DISTRIBUTION OF ROOTS PER SQUARE FOOT OF ROCK-FREE SOIL HORIZON, BY FOREST TYPES

The total number of roots and the number of small roots (below 0.05 inch diameter) are shown separately

(figures 33 and 36) shows that here again the A_2 horizon contained a paucity of roots while horizons on either side supported a greater number. Root numbers in the spruce swamp (figures 34 and 36) decreased rapidly with depth, indicating a possible deficiency of oxygen.

Working on the same plots, Hopkins (1939) identified many of the roots from the soil pits. From these field observations and subsequent laboratory studies, he reached the following conclusions: (1) yellow-birch roots are found at a greater depth than are roots of any other species; (2) spruce

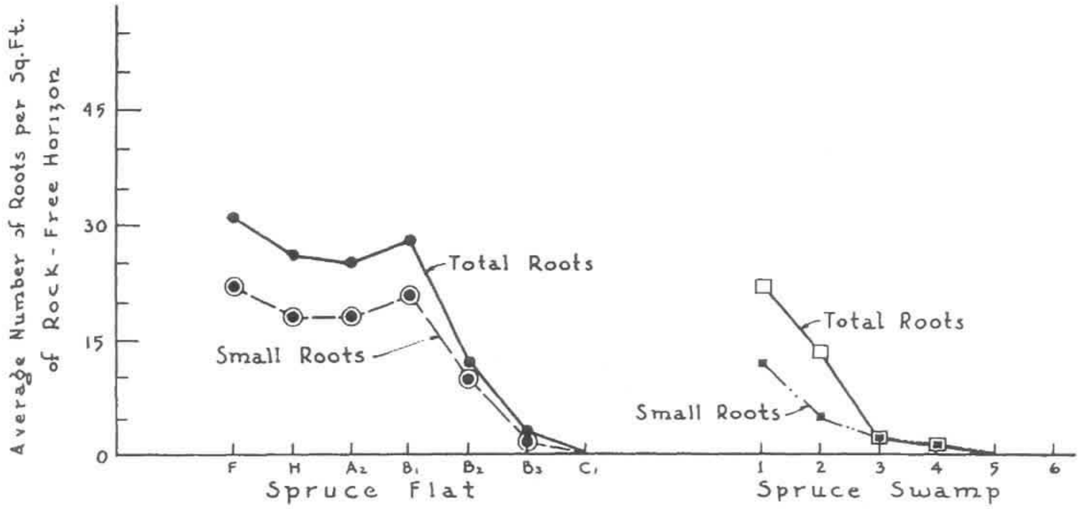

FIGURE 36. NUMERICAL DISTRIBUTION OF ROOTS PER SQUARE FOOT OF ROCK-FREE SOIL HORIZON, BY FOREST TYPES

The total number of roots and the number of small roots (below 0.05 inch diameter) are shown separately

roots are confined to the organic layers; (3) balsam-fir roots are most numerous in the organic layers, but a few penetrate the mineral horizons; (4) the total number of roots is highly correlated with the loss on ignition as well as with the moisture equivalent.

APPLICATION TO FOREST MANAGEMENT

GROWTH RATE

Recknagel (1922), after several years of practical forest-management studies in the Adirondacks and elsewhere, succinctly stated that "the key to forest management is a knowledge of growth." In the present investigation, growth of the principal commercially important species, including sugar maple, beech, yellow birch, spruce, balsam fir, and northern white cedar, was studied, and several practical conclusions may be drawn as a result. These are discussed, by species, in the following paragraphs.

In an old-growth stand, sugar maple made more rapid radial growth during the first 150 years when growing in association with spruce, balsam fir, and hemlock (figure 13, page 19). After this period, however, it forged ahead on the hardwood type until at 230 years the trees averaged 2.4 inches larger in diameter, inside the bark, and 12 feet taller. The factor of greater continued suppression on the hardwood type probably accounted for the slower initial growth on that type. If this is the true explanation, then a stand of sugar maple containing American elm, white ash, and basswood could be expected to respond readily to forest management. With some species, faster growth is decidedly a disadvantage in their utility. In the case of sugar maple, however, increased growth resulting from thinnings will probably increase the specific gravity and consequently those mechanical properties that make this species so valuable for such products as high-grade furniture and flooring.

The cumulative radial growth of beech gave no noticeable variation with site when growing in stands of different composition (figure 14, page 20). The species itself is slow-growing, has very little market value, is frequently unsound, and for many other reasons is an inferior forest tree. It is not disappointing, therefore, to find beech unresponsive to site.

Yellow birch appears to be one of the most widely distributed hardwoods in the Adirondacks. This fact, coupled with the increasing demand for the lumber, makes this species one of the most valuable hardwoods of the region. In the present study, yellow birch made the most rapid radial growth on the spruce-hardwood type (figure 15, page 20) but the greatest total height at maturity on the hardwood type. On the hardwood type, however, competition from sugar maple is keen and the number of yellow-birch trees in old-growth stands is small, and this species may be hard to maintain under these conditions. However, it could be easily maintained, and would make satisfactory growth, on the spruce-hardwood type, where it is usually the most abundant hardwood.

Spruce attained its best radial growth on the spruce flat type (figure 16, page 21), although its maximum height growth at maturity occurred when it was growing in association with sugar maple on the spruce-hardwood type. However, the fact that spruce is hard to maintain on the spruce-hardwood type because of competition from the hardwoods, coupled with its inferior radial growth thereon, confirms the opinion that this species can be managed more economically on some other forest type—for example, on the spruce flat.

Almost the same conclusions can be drawn from the data on balsam-fir growth. Spruce, however, can withstand more competition from the hardwoods than can balsam fir, and therefore is more likely to maintain itself when growing in association with sugar maple, beech, and yellow birch. The radial growth of balsam fir was best on the spruce flat type, and poorest on the spruce swamp (figure 17, page 22). It can be concluded, therefore, that the spruce flat type is the best for the production of both spruce and balsam fir.

The number of northern white cedar trees found in this study was very small, and therefore the data on this species are merely suggestive. The data, indicate, however, that the spruce flat is the best site for northern white cedar (figure 18, page 22).

SITE CLASSIFICATION

Many attempts have been made to measure some factor in the forest that can be correlated with site quality. Total height at a given age or at maturity, basal area, increment in cubic feet per acre, radial growth, and soil characteristics, have all been used and recommended by certain investigators. In this study another factor is added, namely, mean annual increment in pounds per acre. Each is discussed separately in the following paragraphs.

With one exception, total height at maturity gave perfect agreement with the following productivity level:

hardwood > spruce-hardwood > spruce flat > spruce swamp

The one exception was found in the case of balsam fir growing on the spruce-hardwood type. The number of trees measured was probably inadequate, however, and data given by Zon (1914) may be cited to support this contention. Height growth as an index of site quality is to be recommended.

With the assumption that the general-productivity gradient is

hardwood > spruce-hardwood > spruce flat > spruce swamp

the basal areas reported in this investigation did not agree. Neither did they show a great variation as between any of the sites. Therefore, in forests similar to those studied in this investigation, basal area should not be used as a criterion of site quality.

Mean annual increment in cubic feet per acre varies noticeably with site, and for this reason it is to be recommended as an index of site quality. However, it is rather difficult to determine the total age of dense hardwood trees. Growth in cubic feet can be readily converted into commercial equivalents, such as cords. Also, when the volume in cubic feet is determined separately for dominant and co-dominant trees (as in this study), a rough estimate of board-foot volume can be made.

From the increment in cubic feet, the number of pounds of oven-dry wood was determined by calculations involving the specific gravity of the increment borings. The particular advantage offered by this method of site determination lies in the fact that greater variation was found when comparing a predominantly hardwood stand with a stand containing mainly softwoods.

The radial growth of softwoods has been studied for many years by increment-core ring counts. Hardwood growth studies with the same procedure have been limited, however, owing to the difficulty encountered in the use of the increment borer on dense wood. In the present investigation this difficulty was partially overcome by using new instruments and by oiling the shank each time before it was used. The results obtained with the use of increment-core analysis are approximated in only one other way, namely, stump analysis. The latter method is restricted, however, to recent logging operations. Ring analysis is probably the best single method of determining tree growth, and when combined with height and volume it tells the entire growth history. From the standpoint of forest management, radial growth in fully stocked stands is a very useful index; although in open-grown trees with low crowns, rapid radial growth is likely to take place almost independently of site.

When an attempt is made to determine site quality on an area that has been either logged heavily, burned, or cleared, the approach is definitely limited. It is under these conditions that a study of the soil is particularly expedient. However, the interrelationships between tree growth and soil characteristics under equilibrium conditions must first have been studied in the same region. And with some caution in its application, the soil characteristics associated with a given tree response can then be used to predict site quality on denuded areas.

The soil characteristics that were found in this investigation to be associated with a good site are: (1) a fine-mull A horizon with no noticeable development of a gray leached A_2 zone; (2) a hydrogen-ion concentration above 5.0; (3) a chocolate brown, deep, B horizon; (4) only moderately rocky soil; (5) a thin accumulation of organic debris; (6) a perched, moving water table; (7) a southerly exposure.

SUMMARY AND CONCLUSIONS

Growth and closely related data on sugar maple, beech, yellow birch, spruce, balsam fir, and northern white cedar, were obtained on contrasting forest types in the central Adirondacks. Certain soil characteristics were simultaneously measured and related to the growth of the trees. The more salient results are itemized below.

1. The hardwood type was predominantly sugar maple, with an admixture of beech, basswood, yellow birch, white ash, and American elm. The spruce-hardwood type consisted of yellow birch and sugar maple, plus beech, spruce, red maple, balsam fir, and eastern hemlock. The spruce flat and spruce swamp types contained balsam fir, red and black spruce, northern white cedar, yellow birch, paper birch, and red maple. In addition, the swamp type included a few tamaracks.

2. Whenever a species existed on two or more forest types, its total height at maturity was in this order:

hardwood > spruce-hardwood > spruce flat > spruce swamp

The only exception was balsam fir on the spruce-hardwood type. Other data (Zon, 1914) indicate that if more trees had been measured no such inconsistency would have been noted.

3. The basal area of all trees 1 inch d.b.h. and over, was determined for the average acre on each of the forest types investigated. Inasmuch as the greatest variation in basal area between the highest and the lowest value was only about 30 square feet, this method of expressing differences in forest types is not to be recommended. Also, the best site by every other criterion ranked third in basal area. The relative order of basal-area values showed:

spruce-hardwood > spruce flat > hardwood > spruce swamp

4. The specific gravity of the heartwood and the sapwood from 440 softwood and 174 hardwood increment borings was determined and summarized by forest types. Very little difference in specific gravity was found between the forest types, even though variations in radial growth and height growth existed. The specific-gravity values obtained by using increment borings agreed fairly well with, but were slightly higher than, the figures obtained on the same species by standard methods at the Forest Products Laboratory (Markwardt and Wilson, 1935). It would seem that permanent compression by the increment borer was responsible for these higher values.

5. The mean annual increment in cubic feet per acre for all species by forest types supported the original hypothesis of the order of productivity. The forest types ranked as follows:

hardwood > spruce-hardwood > spruce flat > spruce swamp

The variation between the highest and the lowest value amounted to more than 100 per cent. This great variation with site substantiates the opinion that cubic feet per acre per year is a good index of site quality.

6. The relative differences in mean annual increment between the hardwood and the spruce-hardwood forest type were similar, whether the results were expressed in cubic feet or in pounds of oven-dry wood per acre. The same statement holds true for the two softwood plots. However, when a

comparison was made between predominantly hardwood plots and predominantly softwood plots, the increment in pounds showed a greater variation than did the increment in cubic feet. Moreover, heavier wood of the same species is usually superior in mechanical properties to wood of low specific gravity. This greater variation in pounds, combined with the possibility of obtaining an index to the mechanical properties of the wood, adds significance to specific-gravity determinations and to subsequent calculations of the pounds of oven-dry wood per acre. Under the conditions existing in this study, the number of pounds of oven-dry wood is a better site-quality index than the number of cubic feet.

7. Increment borings from 536 softwood and 330 hardwood trees were analyzed and summarized by species and by forest types. The conclusions, based upon the last 50 years or more of radial growth at breast height, inside the bark, are as follows:

Sugar maple : hardwood > spruce-hardwood
Beech : no significant variation with forest type
Yellow birch : spruce-hardwood > hardwood > spruce swamp > spruce flat
Spruce : spruce flat > spruce-hardwood > spruce swamp
Balsam fir : spruce flat > spruce swamp
Northern white cedar : spruce flat > spruce swamp

8. The light intensity was measured at 0, 3, and 6 feet above the forest floor on 4 acres of each of the four forest types. A total of 1200 separate measurements were recorded. The average number of foot-candles of sunlight penetrating the various forest canopies was in this order:

spruce swamp > spruce flat > spruce-hardwood > hardwood

9. The soil type under the hardwood forest belongs to the Brown Podzolic group and is classified as Essex sandy loam. The profile consists of a fine mull over a friable, chocolate brown, deep, B horizon, underlain by compact sandy parent material mixed with Adirondack gneiss. Under the spruce-hardwood type, the soil is a member of the true Podzol group and is classified as Beckett sandy loam. The profile is characterized by deep F and H layers, a conspicuous gray A_2 horizon, a friable rust-brown B horizon, and parent material similar to that under the hardwood type. Soils of the spruce flat and spruce swamp forest types were located in a region where anorthosite is the predominant rock. Profile features of the spruce flat were similar to those of the soil under the spruce-hardwood forest. The swamp consisted of layers of woody, fibrous, and sedimentary peat, underlain by sand at a depth of about 3 feet.

10. The hardwood type occurred on lower southerly slopes at an elevation of about 1900 to 2000 feet. The occurrence of the spruce-hardwood type was confined, in this study, to moderately rolling upland, sloping northerly and at about 1650 feet in elevation. The softwood forest types occurred at an elevation of about 1950 feet, and occupied broad, level to undulating, valley floors.

11. The degree of stoniness was expressed in two ways: (1) the number of pounds of rocks per cubic foot of soil pit; and (2) the percentage

of the volume of the soil pit occupied by rocks. The data are here summarized:

Forest type	Pounds of rocks per cubic foot of soil pit	Per cent of soil-pit volume occupied by rocks	Predominant rock
Spruce-hardwood....	28.1	17.1	Adirondack gneiss
Hardwood..........	22.1	13.4	Adirondack gneiss
Spruce flat..........	12.6	7.7	Anorthosite
Spruce swamp.......	No rocks in peat layers	....	Anorthosite in C horizon

12. The percentages of the various soil separates according to the classification of the International Society of Soil Science was determined on each mineral horizon from nine soil pits. There was almost no difference in the percentage of clay from either the hardwood, the spruce-hardwood, or the spruce flat plots. The A and B horizons from the spruce-hardwood plots, however, contained a slightly higher percentage of silt-plus-clay than did those from the hardwood plots. Calculations from the mechanical-analysis data indicated that the soils would be classified as sandy loam.

13. The hydrogen-ion concentration (pH) of each horizon from sixteen plots was determined with a glass electrode. The pH range was from 3.12 to 5.77. The C_1 horizon was approximately the same for all plots. Listed in order of pH, the types are ranked thus:

hardwood > spruce-hardwood > spruce swamp > spruce flat

14. Nineteen root charts were made, representing the four forest types. The root numbers were then summarized by soil horizons and by five size classes. In the hardwood and spruce swamp forest types, the number of roots per square foot of rock-free soil horizon decreased with increasing depth below the surface. In the other forest types, however, the soils exhibited a gray leached zone in which the roots showed a decided decrease in number.

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